Idaho National Engineering Laboratory Waste Area Groups 1-7 and 10 Technology Logic Diagram (Volume II)

M. C. O'Brien
R. H. Mesurvey
M. Little
J. S. Ferguson
M. C. Gilmore

Published September 1993

EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Office of Environmental Restoration
and Waste Management
Under DOE Idaho Operations Office
Contract DE-AC07-76ID01570

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Foreword

The Idaho National Engineering Laboratory (INEL) Technology Logic Diagram (TLD) was developed to provide a decision support tool that relates Environmental Restoration (ER) and Waste Management (WM) problems at the INEL to potential technologies that can remediate these problems. The TLD uses information from the INEL Environmental Restoration Roadmap Document, the INEL Waste Management Operations Roadmap Document, the (Draft) Oak Ridge National Laboratory Technology Logic Diagram, the Oak Ridge K-25 Site Technology Logic Diagram, and the Hanford Site Wiring Diagram.

The TLD identifies the research, development, demonstration, testing, and evaluation needed to develop these technologies to a state that allows technology transfer and application to an environmental restoration need. It is essential that follow-on engineering and system studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in this TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk to meet the site windows of opportunity.

The TLD consists of three separate volumes:

- * Volume I includes the purpose and scope of the TLD, a brief history of the INEL Waste Area Groups, and environmental problems they represent. A description of the TLD, definitions of terms, a description of the technology evaluation process, and a summary of each subelement, is presented. In addition to these sections, Appendix A contains descriptions and photographs of INEL contaminated sites.
- * Volume II (this volume) describes the overall layout and development of the TLD in logic diagram format. This section addresses the environmental restoration of contaminated INEL sites. Specific INEL problem areas/contaminants are identified along with technology solutions, the status of the technologies, precise science and technology needs, and implementation requirements.
- * Volume III provides the Technology Evaluation Data Sheets (TEDS) for Environmental Restoration and Waste Management (EM) activities that are referenced by a TEDS code number in Volume II. Each of these sheets represents a single logic trace across the TLD. These sheets contain more detail than provided for technologies in Volume II. Data sheets are arranged alphanumerically by the TEDS code number in the upper right corner of each sheet.

Volume II provides the TLDs for ER Waste Area Groups 1-7 and 10 activities at the INEL. Logic paths across the TLD indicate the options available for consideration in planning ER activities. Each section (Characterization, Retrieval, Biological and Chemical Treatment, Thermal and Physical Treatment, and Caps and Barriers) represents a subset of problems or a group of related problems and links these problems to developed and proposed technologies that may prove useful in problem resolution. The diagrams contain summary details about the technology options for the problems/challenges and include estimates of the development, implementation, and capital cost.

Technology evaluations contained in these volumes are based on the best available information during the compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. H. Meserve, INEL Technology Logic Diagram, EG&G Idaho, Inc., P. O. Box 1625, Idaho Falls, ID 83415-3930. FAX (208) 526-1393.

Technology Logic Diagram

Logic Diagrams

Explanation and Understanding

Understanding Key

Key

1. The bold arrow indicates the preferred technology

2. The technologies which have been shaded are applicable to specific INEL contaminated sites, but require research and development activities prior to implementation.

Characterization

The characterization section of this TLD reviews the characterization requirements for INEL environmental restoration activities, identifies applicable characterization technologies, and then evaluates and prioritizes those technologies. In addition, areas where characterization needs are not fully met, or where improvements will result in technical or economic gains, new technology requirements will be identified.

Characterization is broken into the following components:

1. In situ radiological a. In situ measurement of beta/gamma emitters b. Portable gamma ray spectrometry c. Proportional counting d. Small long-range alpha detection (LRAD) e. In situ passive monitors for surface contamination by weak beta radionuclides f. NaI gamma spectroscopy 2. Ex situ radiological (laboratory) a. Waste curie monitoring b. Neutron activation (semi-lab) c. Liquid scintillation counting d. NaI Ge gamma spectroscopy 3. Statistics; data collection a. Optimization of sampling designs b. Artificial intelligence/neural network c. Visual display of statistical information d. Hadamard masking for spatial resolution e. Database management for large data collections f. Statistical methods for spatially correlated data 4. In situ physical a. Laser scattering particle size analysis b. Annular denuder technology c. Ground penetrating radar d. Magnetism e. Electrical and electromagnetic (EM) methods f. Fiber optic camera systems g. Seismic methods (refraction, profiling, reflection) h. Microgravity methods 5. Sampling, sample prep. a. Continuous air monitoring b. Metallographic sample preparation c. Vacuum assisted, reverse flow solvent extraction methods d. Sampling and mixing methods e. Punch cores f. Laser ablation	6. Data assessment a. Correlation by b. 7. In situ chemical a. b. c. d. e. f. g. h. i. 8. Ex situ chemical (laboratory) a. b. c. d. e. f. g. h. i. j. k. l. m. n.	6. Data assessment a. Subsurface complexation b. Auto-correlation optimized multi-variant analysis 7. In situ chemical a. Fluorescence b. Fiber optic chemical sensors c. X-ray fluorescence d. Ion chromatography (IC) e. Laser-ablation inductively coupled plasma atomic emission spectroscopy f. Organic vapor monitoring g. Immunoassay (PCB) h. Gas chromatography (GID, IC, TC) i. Infrared analysis of wastes (FTIR-PAS) 8. Ex situ chemical (laboratory) a. Electron spectroscopy for chemical analysis (ESCA) b. Auger electron spectroscopy (AES) c. X-ray diffraction d. Electron diffraction (ED, SAED, LEED) e. Isotopic dilution mass spectroscopy (IDMS) f. Atomic absorption spectroscopy (AA,AE) g. Inductively-coupled plasma mass spectrometry (ICP-MS) h. Cold vapor (mercury) i. Inductively-coupled plasma spectroscopy (ICP) j. Gas chromatography-mass spectroscopy (GC-MS) k. Direct sampling ion trap mass spectrometry (DSIT-MS) l. Wavelength dispersive x-ray spectroscopy (WDS, WDX, electron microprobe) m. On-line supercritical fluid extraction-multidetector gas chromatography (SFE-GC) n. Secondary ion mass spectrometry analysis (Sims Analysis)

Technology Logic Diagram
CHARACTERIZATION CHARACTERIZATION

Figure 1. Characterization. General. Common to all characterization activities.

CHARACTERIZATION

Figure 1. Characterization (continued).

CHARACTERIZATION

Figure 1. Characterization (continued).

ACTERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Database management for large data collections CHAR 72-IN	Accepted Storage and retrieval of large amounts of data in a cost-effective manner will allow the collection and ready retrieval of all characterization data. This would present full characterization data to clean up organizations, allowing more detailed screening characterization, or would ensure that expensive characterization data is not duplicated unnecessarily, as well as allowing for tracking and trending.	Procedures will need to be developed that will ensure maximum access to the data while ensuring its integrity. Adaptation of existing software to allow for statistical manipulation and visual display.	HP and analytical databases exist on Site. Implementation costs \$200K.	
Visual display of statistical information CHAR 73-IN	Demonstration test and evaluation needed. Integration of statistics software and database system with graphics display capability.	Geographic Information System software is available which comes close to meeting this need. This system would need to be adapted for characterization use. 3-D GIS.	Optimization of computing capacity. Development costs \$500K.	
Statistical methods for spatially correlated data CHAR 75-IN	Accepted. The use of spatial statistics and (geostatistics) has been demonstrated successfully for years in the mining and petroleum industries.	Adaptation from the mining and petroleum industries for use in site characterization. Easy to use software will need to be found or developed.	Optimization of computing capacity. Implementation costs \$300K.	
Artificial intelligence/neural network CHAR 22-IN	Demonstration test and evaluation needed. Allows control of instrumentation, data and interpretive analysis based upon human logic with the processing power and repetitive capabilities of computerized systems. It could enable characterization work to be performed to be optimized on a real-time basis. Also useful for training.	Software and model development for data interpretation, including trending on a real-time basis.	Optimization of computer systems depending on sophistication needed for specific applications. Implementation costs \$500K.	

CHARACTERIZATION

Figure 2. Characterization. Radioactive underground storage tanks, aboveground storage tanks, and associated soils.

Is.

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Elements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration test and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at Oak Ridge.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
	In situ chemical	Fluorescence CHAR 92-IN	Research and development needed. Sensitive technique for many specific applications. Laser technology would enhance sensitivity.	Work with specific contaminants to supplement published fluorescence data. Many off-the-shelf system component items available. Procedures and protocol development. Downsizing for field use. Laser development needed.	Instrument costs, \$300K; Development costs, \$400K.
	Ex situ chemical (laboratory)	Electron spectroscopy for chemical analysis (ESCA) CHAR 1-IN	Accepted. Provides elemental and chemical state information on surface species. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Implementation costs, \$50K. Operating costs, <\$500/sample.
		Auger electron spectroscopy (AES) CHAR 2-IN	Accepted. Provides elemental and spatial profiling information in the surface region. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Method development costs, @ \$200K; Operating costs, <\$500/sample.
		X-ray diffraction CHAR 31-IN	Accepted. Provides identification of crystalline phases in solid samples. Can supply quantitative, stress/strain, and particle size information. Mature technology widely used in industry.	Development. Need studies of model site-specific samples if quantitative analysis required.	Technology available. Development costs, \$100K; Operating costs, >\$100/sample.
		Electron diffraction (ED, SAED, LEED) CHAR 37-IN	Accepted. Mature technology. When used in conjunction with transmission electron microscopy, can provide phase identification of submicron particulates and impurities in host matrix. Asbestos identification. Widely used and accepted by industry.	Development of procedures, quantitative models and data base for site-specific scenarios.	< \$200/sample. Development, \$50K.
	Ex situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
	Data assessment	Subsurface complexation CHAR 45-IN	Demonstration test and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Development. Need to develop models for site-specific contaminants and host matrices.	Implementation costs, \$100K.
	Statistics, Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration test and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs, \$150K.
	Sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration test and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity, assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications, these could be expanded for more general use.	Implementation costs, \$300K for mixing, \$300K for protocols and equipment, 15K.

CHARACTERIZATION ACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION ACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration test and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Could be used in bore-hole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
In situ chemical	Ion chromatography (IC) CHAR 50-IN	Accepted. Able to quickly and accurately determine anions or cations in solution to ppm or ppb concentration. Accepted by EPA and industry.	Development. Selection and set up of most appropriate system for site-specific needs.	Instruments available. Implementation costs, @ \$200K.
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration test and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Development. Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
Sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration test and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
In situ radiological	NaI gamma spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K; and measurement costs <\$25.
Ex situ radiological	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off the shelf"	In current use.
Statistics, Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration test and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K depending on application.
	Vacuum assisted, reverse flow solvent extraction methods. CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration test and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs \$300K for mixing; \$300K for protocols and equipment, 15K.

CHARACTERIZATION
CTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 2. Characterization (continued).

CHARACTERIZATION

Figure 3. Characterization. Nonradioactive sumps, ponds, pits, trenches, rubble piles, etc.

CHARACTERIZATION ACTERIZATION

Figure 3. Characterization (continued).

CHARACTERIZATION

Figure 3. Characterization (continued).

CHARACTERIZATION

Figure 3. Characterization (continued).

CHARACTERIZATION

CHARACTERIZATION

Figure 3. Characterization (continued).

Figure 3. Characterization (continued).

CHARACTERIZATION

Figure 4. Characterization. Radioactive sumps, ponds, pits, trenches, rubble piles, etc.

CHARACTERIZATION CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 4. Characterization (continued).

Figure 4. Characterization (continued)

CHARACTERIZATION ACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION

Figure 4. Characterization (continued).

CHARACTERIZATION

Figure 4. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Implementation costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing, \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K. equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs \$22 to 50K per instrument. Operating costs, <\$25 per test.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.

Figure 4. Characterization (continued).

TERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; Implementation cost, \$250K, and measurement costs <\$25.
In situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features, which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
Ex situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Development Need to develop models for site, specific contaminants and host matrices	Implementation costs, \$100K
Statistics: Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing, \$300K for protocols and equipment, 15K

CHARACTER

Figure 4. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
in situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U ²³⁵ and U ²³⁸ detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K, development cost, \$250K, and measurement costs <\$25.
in situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K. Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K. System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K. System cost, \$100K. Commercial rental equipment is available.
in situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use

Figure 4. Characterization (continued).

ERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Development. Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
	Statistical methods for spatially correlated data. CHAR 75-IN	Accepted. The use of spatial statistics and kriging (geostatistics) has been demonstrated successfully for years in the mining and petroleum industries.	Adaptation from the mining and petroleum industries for use in site characterization. Easy to use kriging software will need to be found or developed.	Optimization of computing capacity. Implementation costs \$300K.
Sampling, sample prep.	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Implementation costs, \$400K.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	Established technology. Minor developments may be needed.	Implementation cost, \$50K.
	Measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.

CHARACTER

Figure 4. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
	NaI gamma spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K; and measurement costs <\$25.
in situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
in situ chemical (laboratory)	Electron spectroscopy for chemical analysis (ESCA) CHAR 1-IN	Accepted. Provides elemental and chemical state information on surface species. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Development costs, \$50K; Operating costs, <\$500/sample.
	Auger electron spectroscopy (AES) CHAR 2-IN	Accepted. Provides elemental and spatial profiling information in the surface region. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Method development costs, @ \$200K; Operating costs, <\$500/sample.
	X-ray diffraction CHAR 31-IN	Accepted. Provides identification of crystalline phases in solid samples. Can supply quantitative, stress/strain, and particle size information. Mature technology widely used in industry.	Development. Need studies of model site-specific samples if quantitative analysis required.	Technology available. Implementation costs, 70K; Operating costs, >\$500/sample.
	Electron diffraction (ED, SAED, LEED) CHAR 37-IN	Accepted. Mature technology. When used in conjunction with transmission electron microscopy, can provide phase identification of submicron particulates and impurities in host matrix. Asbestos identification. Widely used and accepted by industry.	Development of procedures, quantitative models and data base for site-specific scenarios.	< \$200/sample. Development, \$50K.
in situ chemical	Fluorescence CHAR 92-IN	Research and Development needed. Sensitive technique for many specific applications. Laser technology would enhance sensitivity.	Work with specific contaminants to supplement published fluorescence data. Many off-the-shelf system component items available. Procedures and protocol development. Downsizing for field use. Laser development needed.	Instrument costs, \$300K. Development costs, \$400K.
data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Development. Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity, assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs, \$300K for mixing, \$300K for protocols and equipment, 15K.
in situ chemical	Ion chromatography (IC) CHAR 50-IN	Accepted. Able to quickly and accurately determine anions or cations in solution to ppm or ppb concentration. Accepted by EPA and industry.	Selection and set up of most appropriate system for site-specific needs.	Instruments available. Implementation costs, @ \$200K.

Figure 4. Characterization (continued).

ERIZATION

Figure 4. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
in situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science technology needs.	No implementation needs.
in situ chemical (laboratory)	Electron spectroscopy for chemical analysis (ESCA) CHAR 1-IN	Accepted. Provides elemental and chemical state information on surface species. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Development costs, \$50K; Operating costs, <\$500/sample.
	Inductively-coupled plasma mass spectrometry (ICP-MS) CHAR 78-IN	Accepted. Multi-element technology more selective than ICP-AES. Isotopic analysis. Accepted by EPA.	Development in progress to combine with laser ablation for surface analysis.	Technology available. Operating cost, \$100-\$150K per multi-element analysis.
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.

Figure 4. Characterization (continued).

CHARACTERIZATION

Figure 4. Characterization (continued).

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ chemical	Organic vapor monitoring CHAR 5-IN	Accepted. Used routinely in IH monitoring of workplace atmospheres in relations. Accepted by OSHA and industry.	Development. Need to calibrate responses to any unique air contaminants expected at the site.	Normal implementation needs. Instrument costs, \$3 to \$6K each. Operating costs, few \$ per test.
	Fluorescence CHAR 92-IN	Demonstration, testing, and evaluation needed. Sensitive technique for many specific applications. Laser technology would enhance sensitivity.	Work with specific contaminants to supplement published fluorescence data. Many off-the-shelf system component items available. Procedures and protocol development. Downsizing for field use. Laser development needed.	Instrument costs, \$300K; Development costs, \$400K.
Ex situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
In situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Could be used in bore-hole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Development. Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.

Figure 5. Characterization. Nonradioactive spill areas, spill migrations, and unconfined disposal sites.

ERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
Ex situ chemical (laboratory)	Gas chromatography - mass spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Development costs, \$100K.
	On-line supercritical fluid extraction - multidetector gas chromatography (SFE-GC) CHAR 115-IN	Research and development needed. One commercial unit available for total petroleum hydrocarbons in soil. Could cut analysis cost by factor of 4, reduce solvent, contaminated waste, and improve sample turnaround time. Could be expanded to PCBs and other solids.	Optimization for PCBs and hydrocarbons in a single operation, validation and protocol development.	Instrumentation cost, \$60K; Operating costs, <\$500/sample, and development cost, \$250K.
Sampling, sample prep.	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs \$300K for mixing, \$300K for protocols and equipment, 15K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs, \$22 to 50K per instrument. Operating costs, <\$25 per test.
Ex situ chemical (laboratory)	Cold vapor (mercury) CHAR 24-IN	Accepted. In widespread routine use for Hg. Accepted by EPA.	Accepted. In widespread routine use for Hg. Accepted by EPA.	None. Technology available.
Sampling, sample prep.	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs \$300K for mixing, \$300K for protocols and equipment, 15K.
In situ chemical	Ion chromatography (IC) CHAR 50-IN	Accepted. Able to quickly and accurately determine anions or cations in solution to ppm or ppb concentration. Accepted by EPA and industry.	Development. Selection and set up of most appropriate system for site specific needs.	Instruments available. Implementation costs, @ \$200K.

CHARACTERI

Figure 5. Characterization (continued).

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
in situ chemical (laboratory)	Electron spectroscopy for chemical analysis (ESCA) CHAR 1-IN	Accepted. Provides elemental and chemical state information on surface species. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Implementation costs, \$50-K; Operating costs, <\$500/sample.
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs \$300K for mixing, \$300K for protocols and equipment, 15K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
in situ chemical (laboratory)	Atomic absorption spectroscopy (AA, AE) CHAR 76-IN	Accepted. In widespread routine use. Accepted by EPA.	General lab (see text).	Technology available. Operating cost, \$25-50 per analysis.
	Inductively coupled plasma spectroscopy (ICP) CHAR 77-IN	Accepted. Multi-element technology in widespread routine use.	General lab (see text).	Technology available. Operating cost, \$100-\$150K per sample.
	Gas chromatography-mass spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Implementation costs, \$100K.
in situ chemical	Organic vapor monitoring CHAR 5-IN	Accepted. Used routinely in IH monitoring of workplace atmospheres in relations. Accepted by OSHA and industry.	Development. Need to calibrate responses to any unique air contaminants expected at the site.	Normal implementation needs. Instrument costs \$3 to \$6K each. Operating costs.
Sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs \$300K for mixing, \$300K for protocols and equipment.
in situ chemical	Immunoassay (PCB) CHAR 99-IN	Demonstration, testing, and evaluation needed. DOE LMD Field Methods Project has demonstrated 1 ppm sensitivity in soils. Commercially available test kits.	Development. Need for slight adaptation of method for samples other than soils.	Normal development and implementation costs. Capital costs, \$100-\$200K. Development costs, \$200K.
	Gas chromatography (GID, IC, TC) CHAR 100-IN	Accepted. Used routinely for more detailed analysis of workplace atmospheres in near real time. Accepted by OSHA, EPA and industry.	Need to develop specialized procedures for rapid identification of suspect materials.	Instrument costs, \$7 to \$30K each, Implementation costs, \$25-\$100K.

Figure 5. Characterization (continued).

Figure 5. Characterization (continued).

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ chemical (laboratory)	Gas chromatography - mass spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Implementation costs, \$100K.
	Direct sampling ion trap mass spectrometry (DSITMS) CHAR 90-IN	Demonstration, testing, and evaluation needed. Allows rapid determination of organics in air and possibly on surfaces.	Methods development and field testing.	Hardware costs, \$100K; Implementation costs, \$100K.
In situ chemical	Organic vapor monitoring CHAR 5-IN	Accepted. Used routinely in IH monitoring of workplace atmospheres. Accepted by OSHA and industry.	Development. Need to calibrate responses to any unique air contaminants expected at the site.	Normal implementation needs. Instrument costs, \$3 to \$6K each. Operating costs, few \$ per test.

Figure 6. Characterization. Radioactive spill areas, spill migrations, and unconfined disposal sites.

TERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Development costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.

CHARACTERIZATION

Figure 6. Characterization (continued).

ATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K, and measurement costs <\$25.
Physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and non-metallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation costs, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation costs, \$200K; System cost, \$100K. Commercial rental equipment is available.
radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
stics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs, \$22 to 50K per instrument. Operating costs, <\$25 per test.

Figure 6. Characterization (continued).

ERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumenta-	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K, development cost, \$250K, and measurement costs <\$25.
In situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K. System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
Ex situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.

CHARACTERIZATION

Figure 6. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drilled hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity, assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications, these could be expanded for more general use.	Implementation costs. \$300K for mixing, \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted	Commercial instrumentation available	Implementation cost low, \$100K
	Laser ablation CHAR 86-IN	Demonstration, test, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications	Implementation costs are \$100K, equipment costs \$200K
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications	Capital equipment costs \$22 to 50K per instrument. Operating costs, <\$25 per test.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs
	In situ measurement of beta gamma emitters CHAR 51 IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102 IN	Demonstration, testing, and evaluation needed. Reusable TLD like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site specific applications.	Commercial exoelectron reader in hand, materials testing development work \$300K <\$25 per detector

Figure 6. Characterization (continued).

CHARACTERIZATION

Figure 6. Characterization (continued).

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
situ radiological	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
	Nal gamma spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination Nal and Ge detectors \$40K, development cost, \$250K, and measurement costs <\$25.
	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	Modification for vertical, overhead or specific site geometries.	Implementation cost, \$50K.
	Measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None "Off-the-shelf"	In current use.
situ chemical (laboratory)	Electron spectroscopy for chemical analysis (ESCA) CHAR 1-IN	Accepted. Provides elemental and chemical state information on surface species. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Implementation costs, \$50K. Operating costs, <\$500/sample.
	Auger electron spectroscopy (AES) CHAR 2-IN	Accepted. Provides elemental and spatial profiling information in the surface region. Mature technology accepted by industry.	Development of specific procedures and protocols.	Instrument and staff available. Method development costs, @ \$200K. Operating costs, <\$500/sample.
	X-ray diffraction CHAR 31-IN	Accepted. Provides identification of crystalline phases in solid samples. Can supply quantitative, stress-strain, and particle size information. Mature technology widely used in industry.	Need studies of model site-specific samples if quantitative analysis required.	Technology available. Implementation costs, \$100K. Operating costs, >\$100/sample.
	Electron diffraction (ED, SAED, LEED) CHAR 37-IN	Accepted. Mature technology. When used in conjunction with transmission electron microscopy, can provide phase identification of sub-micron particulates and impurities in host matrix. Asbestos identification. Widely used and accepted by industry.	Development of procedures, quantitative models and data base for site-specific scenarios.	< \$2000/sample. Implementation cost, \$50K.

Figure 6. Characterization (continued).

CHARACTERIZATION

Figure 6. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
In situ radiological	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U ²³⁵ and U ²³⁸ detection. Can measure subsurface activity. Technology and instrument.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K, and measurement costs <\$25.
	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
In situ physical	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
In situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
Site assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.

Figure 6. Characterization (continued).

CHARACTER

Figure 6. Characterization (continued).

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumen-	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K, and measurement costs <\$25.
in situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
in situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
	Statistical methods for spatially correlated data CHAR 75-IN	Accepted. The use of spatial statistics and kriging (geostatistics) has been demonstrated successfully for years in the mining and petroleum industries.	Adaptation from the mining and petroleum industries for use in site characterization. Easy to use kriging software will need to be found or developed.	Optimization of computing capacity. Development costs \$300K.
sampling, sample prep.	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.

Figure 6. Characterization (continued).

CHARACTERIZATION

Figure 6. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing, \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand, materials testing development work \$30K, <\$25 per detector.
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K, development cost, \$250K, and measurement costs <\$25.
In situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K. Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K. System cost, \$15K. Commercial rental equipment is available.

Figure 6. Characterization (continued).

TERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
Ex situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K
Statistics, Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications, these could be expanded for more general use.	Implementation costs: \$300K for mixing, \$300K for protocols and equipment, 15K
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available	Implementation cost low, \$100K
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications	Development costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications	Capital equipment costs \$22 to 50K per instrument. Operating costs, <\$25 per test

CHARACTERIZATION

Figure 6. Characterization (continued).

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reuseable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U ²³⁵ and U ²³⁸ detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K, and measurement costs <\$25.
In situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation, \$200K; System cost, \$100K. Commercial rental equipment is available.
In situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use	None. "Off-the-shelf."	In current use.
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
Statistics: Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K
Sampling, sample prep	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.

Figure 6. Characterization (continued).

ERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand, materials testing development work \$300K <\$25 per detector
	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U ²³⁵ and U ²³⁸ detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K, development cost, \$250K, and measurement costs <\$25

CHARACTERIZATION

Figure 6. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and non-metallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
In situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
Off-site assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
Statistics: Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Development costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications	Implementation costs are \$100K. equipment costs \$200K.

Figure 6. Characterization (continued).

CHARACTERIZATION

Figure 6. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Statistics; Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency; and development of portable sampling systems.	Implementation costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted.	Commercial instrumentation available.	Implementation cost low, \$100K.
	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
In situ radiological	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K <\$25 per detector.

Figure 6. Characterization (continued).

TERIZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ physical	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K, and measurement costs <\$25.
	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and non-metallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Development cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Improvement cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence contaminant transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at Oak Ridge.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
Ex situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None "Off-the-shelf."	In current use
Data assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.
Statistics: Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep.	Metallographic sample preparation CHAR 67-IN	Accepted. Widely used method to prepare representative cross-sections of materials. Valuable for contaminant spatial (particularly depth) distribution determinations.	Needs procedure and protocol development for specific matrices and applications.	Implementation costs are 1K-30K, depending on application.
	Vacuum assisted, reverse flow solvent extraction methods CHAR 62-IN	Research and development needed. Solvent is introduced through a drill hole into a porous host matrix and a vacuum device is used to recover solvent plus contaminant through the host matrix.	Laboratory studies for assessment of collection efficiency and development of portable sampling systems.	Implementation costs, \$400K.
	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the qualitative evaluation of nonhomogeneity, assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications, these could be expanded for more general use.	Implementation costs \$300K for mixing; \$300K for protocols and equipment, 15K.
	Punch cores CHAR 83-IN	Accepted	Commercial instrumentation available.	Implementation cost low, \$100K.

CHARACTERIZATION

Figure 6. Characterization (continued).

ZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ radiological	Laser ablation CHAR 86-IN	Demonstration, testing, and evaluation needed. Technique for sampling solid materials by ablating the surface followed by analysis of the removed material. Currently used in ICP-MS. This technology is becoming available for field and more general laboratory use.	Need to develop sampling equipment, procedures and protocols for specific field and laboratory applications.	Implementation costs are \$100K, equipment costs \$200K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
	Proportional counting CHAR 108-IN	Accepted. Sensitive to 100dpm/cm ² . Probes can be made large for wide areas, or small to fit into process piping.	No science & technology needs.	No implementation needs.
	In situ measurement of beta gamma emitters CHAR 51-IN	Accepted. The ability to obtain an accurate measure of gamma emitters for determination of background levels and to monitor small changes in concentration is very important.	Mature technology. Adapt existing equipment, calibrate, optimize procedures, and write protocols to obtain in situ measurements.	Low implementation cost needs.
	In situ passive monitors for surface contamination by weak beta radionuclides CHAR 102-IN	Demonstration, testing, and evaluation needed. Reusable TLD-like chip, small size detectors for radiological monitoring in difficult-to-access locations. Detectors can be deployed in large numbers.	Thorough evaluation for use in mixed surface contamination areas. Testing and evaluation of ceramic exoelectron materials to select most suitable type for site-specific applications.	Commercial exoelectron reader in hand; materials testing development work \$300K. <\$25 per detector.
In situ physical	Portable gamma ray spectroscopy CHAR 106-IN CHAR 112-IN	Accepted. Useful for U235 and U238 detection. Can measure subsurface activity. Technology and instrumentation available.	Correction factors methodology needs to be published.	High resolution Ge detector may be needed to determine correction factors for absorption. Combination NaI and Ge detectors \$40K; development cost, \$250K, and measurement costs <\$25.
	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K. Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K. System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K. System cost, \$100K. Commercial rental equipment is available.
In situ radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf"	In current use
Off-site assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site-specific contaminants and host matrices	Implementation costs, \$100K.

Figure 6. Characterization (continued).

CHARACTERIZATION

Figure 6. Characterization (continued).

ATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
radiological (laboratory)	Liquid scintillation counting CHAR 129-IN	Accepted. Mature technology in current use.	None. "Off-the-shelf."	In current use.
assessment	Subsurface complexation CHAR 45-IN	Demonstration, testing, and evaluation needed. Technology allows modeling of contaminant host interactions to enhance understanding of environmental transport.	Need to develop models for site, specific contaminants and host matrices.	Implementation costs, \$100K.

Figure 7. Characterization. Injection wells, groundwater, and associated plumes.

CHARACTERIZATION

Figure 8. Characterization. Unexploded naval ordnance.

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
in situ physical	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes.	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Demonstration, testing, and evaluation needed. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at INEL.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
	Seismic methods (refraction, profiling, reflection) CHAR 126-IN	Demonstration, testing, and evaluation needed. Refraction and deep reflection have been used successfully for years; however, shallow (<30m) reflection capability is relatively recent. Useful for identification and mapping of geological features which control contaminant migration.	Developed shallow sources should be tested. Techniques should be adapted and used for both vertical and horizontal boreholes.	Implementation cost, \$200K; System cost, \$50K. Commercial rental equipment is available.
	Microgravity methods CHAR 127-IN	Demonstration, testing, and evaluation needed. Gravity methods have been successfully used in mining and petroleum industries. Increased sensitivity is needed for accurate, unambiguous interpretation (microgravity).	Development of increased sensitivity for rapid, cost-effective subsurface detection and mapping. Site-specific development for detection of karst cavities and conduits.	Implementation cost, \$200K; System cost, \$60K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
in situ chemical (laboratory)	Atomic absorption spectroscopy (AA, AE) CHAR 76-IN	Accepted. In widespread routine use. Accepted by EPA.	General lab (see text).	Technology available. Operating cost, \$25-50 per analysis.
	X-ray fluorescence CHAR 6-IN CHAR 98-IN	Accepted. Accepted by the EPA for Level 1 site assessment.	Downsizing for robotics applications.	Implementation cost 100K. Capital equipment costs, 5K-10K.
	Laser-ablation inductively coupled plasma atomic emission spectroscopy CHAR 111-IN	Demonstration, testing, and evaluation needed. No waste. Robotics and automation potential. Demonstrated at Fernald.	Need to tailor to site-specific conditions and validate. Need to increase ablation and portability. (Ames Laboratory.)	Development, \$500K; Equipment, \$500K.
in situ chemical	Infrared analysis of wastes (FTIR-PAS) CHAR 111-IN	Demonstration, testing, and evaluation needed. FTIR-PAS is still developmental but has an excellent chance of becoming proven and demonstrated technology in the near future (within 1 year). FTIR-PAS extends the detection capability of FTIR to also analyze solids and sludges, and is uniquely capable of analyzing explosive molecules and ionic series in an inherently safe way with no special sample preparation. FTIR-PAS requires discreet sampling and analysis methods at present and instrumentation development is needed to provide automatic sampling and to improve the analysis.	FTIR-PAS The methodology for rapid and routinely produced quantitative analysis results from small surrogate waste samples with a minimum of sample handling is required. The results of this work needs to be demonstrated on radioactive wastes and explosive-type wastes under field conditions.	Implementation needs not currently determined.

Figure 8. Characterization (continued).

CHARACTERIZATION

Figure 9. Characterization. Landfills.

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
situ chemical (laboratory)	Gas chromatography - mass spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Development costs, \$100K.
	Direct sampling ion trap mass spectrometry (DSITMS) CHAR 90-IN	Demonstration, testing, and evaluation needed. Allows rapid determination of organics in air and possibly on surfaces.	Methods development and field testing.	Hardware costs, \$100K; Development costs, \$100K.
situ chemical	Organic vapor monitoring CHAR 5-IN	Accepted. Used routinely in IH monitoring of workplace atmospheres. Accepted by OSHA and industry.	Need to calibrate responses to any unique air contaminants expected at the site.	Normal implementation needs. Instrument costs, \$3 to \$6K each. Operating costs, few \$ per test.
Statistics, Data collection	Optimization of sampling designs CHAR 71-IN	Demonstration, testing, and evaluation needed. Appropriate sampling designs can prevent obtaining too little information or spending too much money on a more than adequate number of samples.	Literary searches for finding useful sampling designs from other fields. Development of new statistical methods for sampling design.	Implementation costs \$150K.
Sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.
	Microwave digestion CHAR 19-IN	Accepted. Effective in digesting and extracting trace elements from soils and complex matrices prior to analysis. This is an emerging technology that shows much promise in reducing the amount of waste produced in sample analysis as well as increasing the quality of the data obtained.	Adaptation and optimization for specific applications.	Capital equipment costs: \$22 to 50K per instrument. Operating costs, <\$25 per test.
situ chemical (laboratory)	Atomic absorption spectroscopy (AA, AE) CHAR 76-IN	Accepted. In widespread routine use. Accepted by EPA.	General lab (see text).	Technology available. Operating cost, \$25-50 per analysis.
	Inductively-coupled plasma spectroscopy (ICP) CHAR 77-IN	Accepted. Multi-element technology in widespread routine use.	General lab (see text).	Technology available. Operating cost, \$100-\$150K per sample.
	Inductively-coupled plasma mass spectrometry (ICP-MS) CHAR 78-IN	Accepted. Multi-element technology more selective than ICP-AES. Isotopic analysis. Accepted by EPA.	Development in progress to combine with laser ablation for surface analysis	Technology available. Operating cost, \$100-\$150K per multi-element
	Isotopic dilution mass spectroscopy (IDMS) CHAR 48-IN	Accepted. Mature technology. High sensitivity, particularly suited for measurements of levels of fission products and neutron-capture product at levels as low as 10 ⁻⁷ atoms. Accepted by industry. Technique will give necessary precision for accountability analysis.	No technology development needed. Modification for vertical, overhead or specific site geometries.	Instrumentation available. Development costs, \$100K.
	Cold vapor (mercury) CHAR 24-IN	Accepted. In widespread routine use for Hg. Accepted by EPA.	General lab (see text).	None Technology available.
	Gas chromatography - mass spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Development costs, \$100K.

CHARACTERIZATION

Figure 9. Characterization (continued).

IZATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ chemical	Gas chromatography - mass spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Implementation costs, \$100K.
	Direct sampling ion trap mass spectroscopy (DSITMS) CHAR 90-IN	Demonstration, testing, and evaluation needed. Allows rapid determination of organics in air and possibly on surfaces.	Methods development and field testing.	Hardware costs, \$100K; Implementation costs, \$100K.
	Organic vapor monitoring CHAR 5-IN	Accepted. Used routinely in IH monitoring of workplace atmospheres in relations. Accepted by OSHA and industry.	Development. Need to calibrate responses to any unique air contaminants expected at the site.	Normal implementation needs. Instrument costs, \$3 to \$6K each. Operating costs, few \$ per test.
	X-ray fluorescence CHAR 6-IN CHAR 98-IN	Accepted. Accepted by the EPA for Level 1 site assessment	Downsizing for robotics applications	Implementation cost 100K. Capital equipment costs, 5K-10K.
In situ physical	Laser ablation inductively coupled plasma atomic emission spectroscopy. CHAR 111-IN	Demonstration, testing, and evaluation needed. No waste. Robotics and automation potential. Demonstrated at Fernald.	Need to tailor to site-specific conditions and validate. Need to increase ablation and portability. (Ames Laboratory)	Development, \$500K; Equipment, \$500K.
	Ground penetrating radar CHAR 124-IN	Accepted. Extremely short electromagnetic pulse return interference by both metallic and nonmetallic objects. Useful in locating buried objects.	Improvements in depth of penetration, signal-to-noise and signal processing, particularly antenna design. Could be developed to measure subsurface plumes	Antenna. Implementation cost, \$400K; Systems cost, \$100K. Commercial rental equipment is available.
	Electrical and electromagnetic (EM) methods CHAR 125-IN	Accepted. Useful for mapping site subsurface features which influence containment transport and which might be missed through drilling. Used airborne (Oak Ridge) and on the surface. Could be used in borehole applications and might be developed for actual plume detection.	Development of site-specific techniques, and data handling and imaging methods. LLNL Developed Borehole System could be adapted for use at Oak Ridge.	Implementation cost, \$200K; System cost, \$100K. Commercial rental equipment is available.
	Seismic methods (refraction, profiling, reflection) CHAR 126-IN	Accepted. Refraction and deep reflection have been used successfully for years; however, shallow (<30m) reflection capability is relatively recent. Useful for identification and mapping of geological features which control contaminant migration.	Developed shallow sources should be tested. Techniques should be adapted and used for both vertical and horizontal boreholes.	Implementation cost, \$200K; System cost, \$50K. Commercial rental equipment is available.
	Microgravity methods CHAR 127-IN	Research and development needed. Gravity methods have been successfully used in mining and petroleum industries. Increased sensitivity is needed for accurate, unambiguous interpretation. Microgravity has been used at the K-25 Site.	Development of increased sensitivity for rapid, cost-effective subsurface detection and mapping. Site-specific development for detection of karst cavities and conduits.	Development cost, \$200K; System cost, \$60K. Commercial rental equipment is available.
	Magnetics CHAR 128-IN	Accepted. Useful for detecting buried ferrous metal objects. Aerial survey completed in Oak Ridge.	Development of methods to minimize interference.	Implementation cost, \$200K; System cost, \$15K. Commercial rental equipment is available.
Sampling, sample prep	Sampling and mixing methods CHAR 81-IN	Demonstration, testing, and evaluation needed. Standard procedures using portable field units are needed to "mix" particulate matter quickly and effectively. Protocols for assessment of nonhomogeneous waste forms have not yet been developed.	Development of protocols for the quantitative evaluation of homogeneity; assessment of commercially available and the probable development of portable mixing equipment. Procedures have been developed for individual applications; these could be expanded for more general use.	Implementation costs: \$300K for mixing; \$300K for protocols and equipment, 15K.

Figure 9. Characterization (continued).

ATION

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
chemical	Gas chromatography - mass Spectroscopy (GC-MS) CHAR 88-IN	Accepted. EPA approved technique for organic compound identification can provide rapid identification.	Improved sampling protocols for rapid turn around analysis. Protocols for automated instrumentation.	Capital costs, \$300K; Implementation costs, \$100K.
	Direct sampling ion trap mass spectrometry (DSITMS) CHAR 90-IN	Demonstration, testing, and evaluation needed. Allows rapid determination of organics in air and possibly on surfaces.	Methods development and field testing.	Hardware costs, \$100K; Implementation costs, \$100K.
	Organic vapor monitoring CHAR 5-IN	Accepted. Used routinely in IH monitoring of workplace atmospheres. Accepted by OSHA and industry.	Development. Need to calibrate responses to any unique air contaminants expected at the site.	Normal implementation needs. Instrument costs, \$3 to \$6K each. Operating costs, few \$ per test.
	X-ray fluorescence CHAR 6-IN CHAR 98-IN	Accepted. Accepted by the EPA for Level 1 site assessment.	Downsizing for robotics applications.	Implementation cost 100K. Capital equipment costs, 5K-10K.
	Laser-ablation inductively coupled plasma atomic emission spectroscopy CHAR 111-IN	Demonstration, testing, and evaluation needed. No waste. Robotics and automation potential. Demonstrated at Fernald.	Need to tailor to site-specific conditions and validate. Need to increase ablation and portability. (Ames Laboratory)	Development, \$500K; Equipment, \$500K.

Retrieval

The Retrieval Section of this TLD identifies retrieval technology options applicable to (e.g., concrete, metal, and rubble) soil, and sludge. The technology status, science and technology

After the waste has been retrieved, treatment and disposal issues must be addressed. Disposal options are addressed in the Caps and Barriers section.

Options for retrieval processes have been divided into two basic types, manual and remote.

1. Manual
 - a. Manual excavator
 - b. Manual backhoe
 - c. Manual motor grader
 - d. Manual dozer
 - e. Containment structures
 - f. Hydraulic shear
 - g. Hydraulic ram
 - h. Scrabbler
 - i. Manual vapor vacuum
 - j. Manual concrete saw
 - k. Trencher
2. Remote
 - a. Teleoperated excavation equipment

eval

licable to environmental restoration activities. Waste and media to be retrieved include debris, e and technology needs, and implementation needs are discussed for each technology identified.

addressed. Treatment options are included in the Biological/Chemical and Thermal/Physical sec-

ual and remote, and the subcategories of the two processes are shown below.

RETRIEVAL

Figure 1. Retrieval. Radioactive underground storage tanks, aboveground storage tanks, and associated soils.

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations. Application is directly related to the remediation of problems similar to the identified site specific work tasks.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
	Manually operated dozer RETR ME-005	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lb.) and are working with "front end shovels" and "backhoes."	Typically "tethered" excavation equipment" (umbilical cord carries electrical power, control, and communications.) (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Grinding equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
Reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities...can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
	Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities...can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.

Figure 1. Retrieval (continued).

RETRIEVAL

Figure 1. Retrieval (continued).

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lb.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment (umbilical cord carries electrical power, control, and communications.) (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lb.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment (umbilical cord carries electrical power, control, and communications.) (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Manually operated backhoe w/extended boom may be required to remove sludge from tank, once excavated

Figure 1. Retrieval (continued).

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required.)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/provided for this operation. Electrical and air supply systems would be required.
Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer", another attachment for downsizing larger concrete structures. 3) Tanks will be downsized with conventional plasma-arc or gas torches.	Technology has no science or technology needs for this application.	Requires applicable excavation equipment with required hydraulics capabilities...can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
	Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	Technology has no science or technology needs for this application.	Requires applicable excavation equipment with required hydraulics capabilities...can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radioactive contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual pump/vacuum	Vacuum pump RETR VAC-001	Accepted. Off the shelf technology. Liquid extraction pumping and collection system for removal of tank liquids and sludge. These are commercially available.	None	Low implementation costs. These are commercially available and can be designed for specific site requirements.

RETRIEVAL

Figure 1. Retrieval (continued).

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated motor grader RETR ME-004	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
Containment	Containment structures RETR CTMNT 001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million

Figure 1. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
	Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.
	Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small-large concrete structures 2) Less versatile than the	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated dozer RETR ME-005	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated motor grader RETR ME-004	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, tele-operated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million

Figure 1. Retrieval (continued).

RETRIEVAL

Alternative	Technologies	Status	Science and Technology Needs	Implementation Needs
Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed
	Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.
	Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radioactive contamination particulate spread	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes"	Typically "tethered excavation equipment" (umbilical cord carries electrical power control and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million
Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.

RETRIEVAL

Figure 1. Retrieval (continued).

RETRIEVAL

Figure 1. Retrieval (continued).

RETRIEVAL

ats	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities... can be mounted on "skid-steer loader" to "backhoe". A water spray system for confinement of radioactive contaminated materials may be needed.
		Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.
		Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
	Manual pump vacuum	Vacuum pump RETR VAC-001	Accepted. Off the shelf technology. Liquid extraction pumping and collection system for removal of tank liquids and sludge. These are commercially available.	None	Low implementation costs. Pumping and collection systems should be evaluated and selected on a site specific basis.
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings, and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
		Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
		Manually operated dozer RETR ME-005	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).

Figure 1. Retrieval (continued).

RETRIEVAL

Elements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Manually operated motor grader RETR ME-004	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes"	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
	Containment	Containment structures RETR CTMNT 001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation		Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated motor grader RETR ME-004	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes"	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
	Containment	Containment structures RETR CTMNT 001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system

RETRIEVAL

Figure 1. Retrieval (continued).

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated dozer RETR ME-005	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated motor grader RETR ME-004	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, tele-operated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.

Figure 2. Retrieval. Nonradioactive sumps, ponds, pits, trenches, rubble piles, etc.

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated motor grader RETR ME-004	Accepted 1) Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver. 2) Not particularly well suited for large and deep excavation work.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Trenching equipment	Manually operated trencher RETR ME-006	Accepted 1) One of the primary choices for large excavation operations - "total retrieval". Most productive equipment for collecting and moving large volumes of soils. 2) "Hydraulic pan" or "paddle-wheel" are two typical types of scrapers.	No science and technology needs. Off the shelf technology.	Independent excavation equipment. A water spray system for confinement of radioactive contaminated materials (loose soil and dust) would need to be developed.
Containment	Containment structures RETR CTMNT-001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radioactive contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).

Figure 2. Retrieval (continued).

RETRIEVAL

ments	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted 1) Limited application for smaller quantities of contaminated concrete 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid steer loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
		Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation	No new scientific investigation and/or technological development is necessary for this application	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations
		Manually operated hydraulic ram RETR SR-003	Accepted 1) Secondary attachment to backhoe for downsizing of small large concrete structures 2) Less versatile than the hydraulic shear	No new scientific investigation and/or technological development is necessary for this application	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
	Containment	Containment structures RETR CTMNT-001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radioactive contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted 1) Limited application for smaller quantities of contaminated concrete 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures	No new scientific investigation and/or technological development is necessary for this application	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid steer loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.

Figure 2. Retrieval (continued).

ts

RETRIEVAL

Figure 3. Retrieval. Radioactive sumps, ponds, pits, trenches, rubble piles, etc.

RETRIEVAL

Alternative	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME 003	Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME 001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Remote excavation equipment	Teleoperated excavation equipment RETR RE 001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "leathered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million.
Scabbling equipment	Manually operated scabbler RETR SCA 001	Accepted 1) Limited application for smaller quantities of contaminated concrete 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR 001	Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. Can be mounted on "skid steer loader" to "front end excavator" to "backhoe". A water spray system for confinement of radioactive contaminated materials may be needed.
	Manually operated concrete saw RETR SR 002	Accepted 1) Limited application for smaller downsizing concrete operations 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.
	Manually operated hydraulic ram RETR SR 003	Accepted 1) Secondary attachment to backhoe for downsizing of small large concrete structures 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
Containment	Containment structures RETR CIMNT 001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specially item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME 003	Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).

Figure 3. Retrieval. (continued).

RETRIEVAL

ments	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
	Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation		Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
		Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercial, available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
		Manually operated dozer RETR ME-005	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
		Manually operated motor grader RETR ME-004	Accepted. Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
	Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.

Figure 3. Retrieval (continued).

RETRIEVAL

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed
		Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations
		Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
	Containment	Containment structures RETR CTMNT 001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radioactive contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
	Manual pump/vacuum	Vacuum pump RETR VAC 001	Accepted Available off the shelf technology Liquid extraction pumping and collection system for removal of tank liquids and sludge	None	Low implementation costs Pumping and collection systems should be evaluated and selected on a site specific basis

Figure 3. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Remote Excavation equipment may be used for high Radiation soil removal. Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, tele-operated controls systems, unknown maintenance requirements) Cost \$2-\$4 million
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Normal implementation needs. Contamination collection barriers. Rough HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.
		Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.
		Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.
	Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.
		Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.

Figure 3. Retrieval (continued).

RETRIEVAL

Alternative	Technologies	Status	Science and Technology Needs	Implementation Needs
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes"	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
Containment	Containment structures RETR CTMNT-001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes"	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
Containment	Containment structures RETR CTMNT-001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)

RETRIEVAL RETRIEVAL

Figure 3. Retrieval (continued).

Figure 3. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Manual excavation	Manually operated backhoe RETR ME 003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME 001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Remote excavation equipment	Teleoperated excavation equipment RETR RE 001	Demonstration, testing, and evaluation needed Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes"	Typically "lathered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost \$2-\$4 million
Scabbling equipment	Manually operated scabbler RETR SCA 001	Accepted 1) Limited application for smaller quantities of contaminated concrete 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs cost effectiveness	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs Contamination collection barrels, Rough HEPA filters, and vacuum systems would need to be supplied procured for this operation. Electrical and air supply systems would be required
Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR 001	Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures	No new scientific investigation and/or technological development is necessary for this application	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid steer loader" to "front end excavator" to "backhoe" A water spray system for confinement of radioactive contaminated materials may be needed
	Manually operated concrete saw RETR SR 002	Accepted 1) Limited application for smaller downsizing concrete operations 2) Very labor intensive downsizing operation	No new scientific investigation and/or technological development is necessary for this application	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations
	Manually operated hydraulic ram RETR SR 003	Accepted 1) Secondary attachment to backhoe for downsizing of small large concrete structures 2) Less versatile than the hydraulic shear	No new scientific investigation and/or technological development is necessary for this application	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed
Containment	Containment structures RETR CTMNT 001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation	Manually operated backhoe RETR ME 003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME 001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)

RETRIEVAL

Figure 3. Retrieval (continued).

RETRIEVAL

Figure 3. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment..	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment would not be typically required for these site conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
OTHER NOTES: These liquids would be dispersed throughout the soil matrix and would be at most a form of sludge. The retrieval equipment technology outlined above should be sufficient.				
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Containment	Containment structures RETR CTMNT-001	Accepted. Containment would not be typically required for these site conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements.) Cost: \$2-\$4 million
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
Containment	Containment structures RETR CTMNT-001	Accepted. Containment May be required for these site conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread. (130'x200' structure costs approximately \$370,000)	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system and HVAC w/HEPA filters

Figure 4. Retrieval. Nonradioactive spill areas, spill migrations, and unconfined disposal sites.

RETRIEVAL

Figure 4. Retrieval (continued).

RETRIEVAL

at	ents	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
			Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Containment	Containment structures RETR CTMNT-001		Accepted. Containment would not be typically required for these site conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
n	Manual excavation	Manually operated backhoe RETR ME-003		Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated excavator RETR ME-001		Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	OTHER NOTES: This contamination is under building CFA-623 and surrounding asphalt pad! Under structure excavation can be accomplished, but it is very expensive due to the shoring, jacking, and restrictive work space.					
Th mpl	Manual excavation	Manually operated backhoe RETR ME-003		Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
on		Manually operated excavator RETR ME-001		Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	OTHER NOTES: This contamination is in a small concrete basin and only has a manhole sized access! Typical retrieval equipment cannot be readily applied here due to the size restriction. This requires manual labor with equipment assistance.					
S ent	Manual excavation	Manually operated backhoe RETR ME-003		Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated excavator RETR ME-001		Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
tion		Manually operated dozer RETR ME-005		Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)

Figure 4. Retrieval (continued).

RETRIEVAL

ents	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Manually operated motor grader RETR ME-004	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes"	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, tele-operated controls systems, unknown maintenance requirements) Cost \$2 \$4 million.
	Containment	Containment structures RETR CTMNT-001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
	Manual vapor vacuum	Vapor vacuum extraction pump RETR VAC-001	Accepted 1) Primarily utilized to remove vapors from tanks 2) Alternate systems would include liquid extraction pumping and collection systems for the removal of tank liquids and sludge. These are commercially available and/or can be specifically designed for the work task.	None	Low implementation costs These are commercially available and can be designed for specific site requirements

Figure 5. Retrieval. Radioactive spill areas, spill migrations, and unconfined disposal sites.

Figure 5. Retrieval (continued).

Figure 5. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. Can be mounted on "skid/ster loader" to "front end excavator" to "backhoe". A water spray system for confinement of radioactive contaminated materials may be needed.
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lb.) and are working with "front end shovels" and "backhoes".	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated control systems, unknown maintenance requirements).
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes".	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements). Cost: \$2-\$4 million.
Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barriers, Rough HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.

Figure 5. Retrieval (continued).

RETRIEVAL

Figure 5. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Containment	Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set-up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Manually operated excavator RETR ME-001	Accepted. Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations.	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications). (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements.) Cost: \$2-\$4 million.
Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs. cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, Rough/HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required.
Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid/ster loader" to "front end excavator" to "backhoe". A water spray system for confinement of radioactive contaminated materials may be needed.
	Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.
	Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
Containment	Containment structures RETR CTMNT-001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.

Figure 5. Retrieval (continued).

RETRIEVAL

Figure 5. Retrieval (continued).

RETRIEVAL

Elements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, HEPA filters, and vacuum systems would need to be procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid/ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
		Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.
		Manually operated hydraulic ram RETR SR-003	Accepted. 1) Secondary attachment to backhoe for downsizing of small/large concrete structures. 2) Less versatile than the hydraulic shear.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.
	Containment	Containment structures RETR CTMNT 001	Accepted. Containment may be required based upon weather working conditions or risk of contamination spread.	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radioactive contamination particulate spread.	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system.
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted. 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.).	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required).
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment.	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes."	Typically "tethered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost \$2-\$4 million.
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted. 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs cost effectiveness.	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks.	Normal implementation needs. Contamination collection barrels, HEPA filters, and vacuum systems would need to be procured for this operation. Electrical and air supply systems would be required.
	Size reduction equipment	Hydraulic powered shear attachment (Utilized with backhoe) RETR SR-001	Accepted. 1) Primary attachment to backhoe for downsizing of metals and smaller concrete. 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures.	No new scientific investigation and/or technological development is necessary for this application.	Requires applicable excavation equipment with required hydraulics capabilities. can be mounted on "skid ster loader" to "front end excavator" to "backhoe." A water spray system for confinement of radioactive contaminated materials may be needed.
		Manually operated concrete saw RETR SR-002	Accepted. 1) Limited application for smaller downsizing concrete operations. 2) Very labor intensive downsizing operation.	No new scientific investigation and/or technological development is necessary for this application.	Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations.

Figure 5. Retrieval (continued).

RETRIEVAL

Figure 5. Retrieval (continued).

RETRIEVAL

nts	Alternatives	Technologies	Status *	Science and Technology Needs	Implementation Needs
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks.	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated dozer RETR ME-005	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated motor grader RETR ME-004	Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes"	Typically "leathered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
	Containment	Containment structures RETR CTMNT-001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
	Manual excavation	Manually operated backhoe RETR ME-003	Accepted 1) Primary choice for selective excavation. 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
		Manually operated excavator RETR ME-001	Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations	No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks	Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)
	Remote excavation equipment	Teleoperated excavation equipment RETR RE-001	Demonstration, testing, and evaluation needed. Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs) and are working with "front end shovels" and "backhoes"	Typically "leathered excavation equipment" (umbilical cord carries electrical power, control, and communications) (Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements) Cost: \$2-\$4 million
	Scabbling equipment	Manually operated scabbler RETR SCA-001	Accepted 1) Limited application for smaller quantities of contaminated concrete. 2) Very labor intensive operation and burial volumes currently not restricted. Waste minimization planning vs cost effectiveness	Technology has no science or technology needs for this application, equipment sized to meet the identified site specific work tasks	Normal implementation needs. Contamination collection barriers. Rough HEPA filters, and vacuum systems would need to be supplied/procured for this operation. Electrical and air supply systems would be required

RETRIEVAL

Figure 5. Retrieval (continued).

RETRIEVAL

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Size reduction equipment	<p>Hydraulic-powered shear attachment (Utilized with backhoe) RETR SR-001</p> <p>Manually operated concrete saw RETR SR-002</p> <p>Manually operated hydraulic ram RETR SR-003</p>	<p>Accepted 1) Primary attachment to backhoe for downsizing of metals and smaller concrete 2) Hydraulic "concrete pulverizer" another useful attachment for downsizing larger concrete structures</p> <p>Accepted 1) Limited application for smaller downsizing concrete operations 2) Very labor intensive downsizing operation</p> <p>Accepted 1) Secondary attachment to backhoe for downsizing of small-large concrete structures 2) Less versatile than the hydraulic shear</p>	<p>No new scientific investigation and/or technological development is necessary for this application</p> <p>No new scientific investigation and/or technological development is necessary for this application</p> <p>No new scientific investigation and/or technological development is necessary for this application</p>	<p>Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed.</p> <p>Portable vacuum, air, and water supply systems are needed to support this type of concrete cutting operations</p> <p>Requires applicable excavation equipment with required hydraulics capabilities. A water spray system for confinement of radioactive contaminated materials may be needed</p>
Containment	Containment structures RETR CTMNT 001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system
Manual excavation	<p>Manually operated backhoe RETR ME 003</p> <p>Manually operated excavator RETR ME 001</p> <p>Manually operated dozer RETR ME 005</p> <p>Manually operated motor grader RETR ME 004</p>	<p>Accepted 1) Primary choice for selective excavation 2) Provides a wide range of mobility and versatility to hydraulic attachments (shear, ram, etc.)</p> <p>Accepted Currently accepted and proven technology used by the construction and demolition industries for selective excavation, trenching, larger excavation sites, and demolition operations</p> <p>Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.</p> <p>Accepted Not particularly well suited for selective excavation work. Requires larger areas to operate and maneuver.</p>	<p>No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks</p> <p>No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment sized to meet the identified site specific work tasks</p> <p>No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks</p> <p>No new scientific investigation and/or technological development is necessary to fully implement commercially available equipment, sized to meet the identified site specific work tasks</p>	<p>Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)</p> <p>Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)</p> <p>Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)</p> <p>Independent excavation equipment (diesel engine operation, hydraulic systems, limited maintenance required)</p>
Remote excavation equipment	Teleoperated excavation equipment RETR RE 001	Demonstration, testing, and evaluation needed Limited radioactivity of area does not warrant "remote" excavation equipment	Technology development groups are utilizing larger class machines (54,000 to 75,000 lbs.) and are working with "front end shovels" and "backhoes."	Typically "leathered excavation equipment" (umbilical cord carries electrical power, control, and communications). Electric motor operation, hydraulic systems, teleoperated controls systems, unknown maintenance requirements. Cost: \$2-\$4 million
Containment	Containment structures RETR CTMNT 001	Accepted Containment may be required based upon weather working conditions or risk of contamination spread	Large "temporary" containment structures are currently available commercially which require limited or no footings and provide pressurized containment for control of radiological contamination particulate spread	Subcontractor "set up" and "removal" would be utilized for "specialty item" such as this. Support power and equipment for pressurized system

RETRIEVAL

Figure 6. Retrieval. Unexploded naval ordnance.

RETRIEVAL

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--	--------------	--------------	--------	------------------------------	----------------------

RETRIEVAL RETRIEVAL

Figure 7. Retrieval. Landfills.

Biological and Chemical

The Biological and Chemical Treatment section of this TLD addresses technologies. It identifies and evaluates biological and chemical treatment options. The degree to which each process is consistent with the process, availability, etc.

Biological and chemical treatment processes are divided into the following technologies:

1. In situ soil remediation
 - a. Plant uptake of metals/radionuclides
2. Soil Washing/Leaching
 - a. Chemical washing
 - b. Direct biological leaching
 - c. Indirect biological leaching
3. Inorganic Concentration from Liquids
 - a. Bioaccumulation
 - b. Bioprecipitation
 - c. Chemical precipitation
4. Organically-contaminated soil remediation
 - a. Landfarming
 - b. Slurry/liquid bioremediation
 - c. Subsurface soil remediation.
- 5.
- 6.

Chemical Treatment

These technologies for processing wastes generated during cleanup of INEL contaminated sites. The degree to which a recommended treatment process is appropriate is based on cost, experi-

Following technology options.

5. Ex situ chemical treatment
 - a. Chemical washing
 - b. Nitric acid/EDTA wash
 - c. Dilute nitric acid wash
 - d. Surfactant wash
 - e. Hot nitrogen stripping
 - f. Cold dilute potassium hydroxide wash
6. Nitrates-contaminated media remediation
 - a. Slurry/liquid bioremediation

Figure 1. Biological and chemical treatment. Radioactive underground storage tanks, aboveground storage tanks, and associated soils.

PHYSICAL AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

em
ite. treatment → No biological or chemical technology identified for this site.

associated soils.

BIOLOGICAL AND CHEMICAL AND CHEMICAL TREATMENT

Figure 1. Biological and chemical treatment (continued).

Figure 1. Biological and chemical treatment (continued).

PHASED CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

Alternative treatment	Inorganic concentration from liquids	Chemical precipitation BICH-I-CP	Research and development needed. This technology is currently available on the market. The method involves adding a chemical or chemicals to the contaminated liquid which will result in complexation or reduction and precipitation are forms of iron, sulfide, and hydroxide. This technology often requires close control of the solution pH during operation and secondary treatment to collect and dispose of the resulting sludge.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and pH levels will be required by a case by case basis. Developing a precipitation system which would be capable of targeting specific contaminants selectively rather than nonselectively would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions.
Alternative treatment	Inorganic concentration from liquids	Chemical precipitation BICH-I-CP	Research and development needed. This technology is currently available on the market. The method involves adding a chemical or chemicals to the contaminated liquid which will result in complexation or reduction and precipitation are forms of iron, sulfide, and hydroxide. This technology often requires close control of the solution pH during operation and secondary treatment to collect and dispose of the resulting sludge.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and pH levels will be required by a case by case basis. Developing a precipitation system which would be capable of targeting specific contaminants selectively rather than nonselectively would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions.
Alternative treatment	Inorganic concentration from liquids	Chemical precipitation BICH-I-CP	Research and development needed. This technology is currently available on the market. The method involves adding a chemical or chemicals to the contaminated liquid which will result in complexation or reduction and precipitation are forms of iron, sulfide, and hydroxide. This technology often requires close control of the solution pH during operation and secondary treatment to collect and dispose of the resulting sludge.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and pH levels will be required by a case by case basis. Developing a precipitation system which would be capable of targeting specific contaminants selectively rather than nonselectively would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions.

Figure 1. Biological and chemical treatment (continued).

logic chemical treatment → No biological or chemical technology

logic chemical treatment → No biological or chemical technology

Figure 1. Biological and chemical treatment (continued).

ND CHEMICAL TREATMENT

nts	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Indirect biological leaching BICH-I-BL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC2	Demonstration, testing, and evaluation needed. This technology is limited to soils and most likely ineffective for contaminated concrete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.
	Ex situ chemical treatment	Nitric acid/EDTA wash BICH-017A	Research and development needed. This is a developing technology that can be applied, but is currently very costly. Research may be required to optimize the process. The amalgam electro-winning is a developing technology that is currently being researched at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.

BIOLOGICAL AND CHEMICAL AND CHEMICAL TREATMENT

Figure 1. Biological and chemical treatment (continued).

Figure 1. Biological and chemical treatment (continued).

ND CHEMICAL TREATMENT

nts

Alternatives

Technologies

Status

Science and Technology Needs

Implementation Needs

Figure 1. Biological and chemical treatment (continued).

Indirect biological leaching
BICH-I-BL

Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.

The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.

Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

In situ soil remediation

Plant uptake of metals/radionuclides
BICH-I-PLC

Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.

The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.

The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.

Ex situ chemical treatment

Chemical washing (cesium, strontium, and plutonium)
BICH-004

Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.

Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.

Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up will also be required.

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 1. Biological and chemical treatment (continued).

Figure 1. Biological and chemical treatment (continued).

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
In situ soil remediation	Indirect biological leaching BICH-1-BL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bio-precipitation, ion exchange, etc.
	Plant uptake of metals/radionuclides BICH-1-PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.
	Ex situ chemical treatment	Chemical washing (cesium and strontium) BICH-012	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.

R CHEMICAL TREATMENT

Alternatives.	Technologies	Status	Science and Technology Needs	Implementation Needs
	Dilute nitric acid wash BICH-020	Research and development needed. Chemical washing has been an accepted method for several years. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.
Soil washing/leaching	Chemical washing BICH-1-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH-1-DRL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores. (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil and will necessarily contain the suspension of spent microbes from the reactor, since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated conditions. Specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include: the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of contaminants to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g. tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g. leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 1. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Indirect biological leaching BICH-I-BL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC2	Demonstration, testing, and evaluation. This technology is limited to soils and most likely ineffective for contaminated concrete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.
Ex situ chemical treatment	Dilute nitric acid wash BICH-020	Research and development needed. Chemical washing has been an accepted method for several years. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.

Figure 1. Biological and chemical treatment (continued).

PHYSICAL AND CHEMICAL TREATMENT

Contaminants	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Inorganic and organic chemicals	Soil washing/leaching	Chemical washing BICH-I-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.
		Direct biological leaching BICH-I-DL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Indirect biological leaching BICH-I-IL	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry phase mixed reactors to leach the metals, and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL

Figure 1. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Figure 1. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	<p>→ Direct biological leaching B/CH-I-DBL2B</p>	<p>→ Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost-effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils and for mercury, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.</p>	<p>→ Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.</p>	<p>→ Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.</p>
	<p>→ Indirect biological leaching B/CH-I-IBL2B</p>	<p>→ Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil-contaminant specific and would require evaluation on a case by case basis.</p>	<p>→ The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation (specifically, the ability to solubilize and remove mercury). The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.</p>	<p>→ Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.</p>

BIOLOGICAL AND CHEMICAL AND CHEMICAL TREATMENT

Figure 1. Biological and chemical treatment (continued)

BIOLOGICAL AND CHEMICAL TR

Figure 1. Biological and chemical treatment (continued).

D CHEMICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--	--------------	--------------	--------	------------------------------	----------------------

ment → No biological or chemical technology
identified for this site

ment → No biological or chemical technology
identified for this site

ment → No biological or chemical technology
identified for this site

BIOLOGICAL AND CHEMICAL

Figure 2. Biological and chemical treatment. Nonradioactive sumps, ponds, pits, trenches, rubble piles, etc.

BIOLOGICAL AND CHEMICAL TR

Figure 2. Biological and chemical treatment (continued).

5 CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH-I-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.
	Direct biological leaching BICH-I-DBL	Research and development needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non-ore like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange etc.
	Indirect biological leaching BICH-II-IBL	Research and development needed. Specific microbial cultures would be grown for collection of metabolically produced acids, organic or inorganic, and/or other chelators. These products would be added to the contaminated soil in slurry phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. The leaching process is relatively rapid and would require a very short residence time of between ten minutes and two hours. The applicability of this technology is very likely site and contaminant specific and would require evaluation on a case by case basis.	The applicability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to the type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove at least as many other known technology.	Hardware requirements for tanks, mixers, pH meters, pumps, augers are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange etc.

Figure 2. Biological and chemical treatment (continued).

CAL AND CHEMICAL TREATMENT

Elements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Ex situ chemical treatment	Surfactant wash Dilute nitric acid wash BICH-034	Research and development needed. Chemical washing has been an accepted method for several years. Amalgam electro-winning is not commercially available. This technology is being developed at the INEL. The technologies mentioned here have not been used in this capacity before, therefore, there will be some process modifications required.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electro-winning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.
Ex situ chemical treatment	Organically contaminated soil remediation	Slurry liquid bioremediation BICH O-SB2	Demonstration, testing, and evaluation needed. This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred tank (as a liquid slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge liquid for discharge.	The scientific needs for application of this technology include the bench scale tests required to define the optimal operating parameters for the specific remediation need. Additionally, the impacts of lead and other inorganic contaminants on this process will need to be assessed.	Hardware requirements to implement this technology are already available on the market. This technology will need to be coupled with other unit processes targeting the inorganic contaminant fraction.
	Soil washing/leaching	Chemical washing BICH I-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Direct biological leaching BICH I-DRL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores. 40% of the U.S. copper is produced biologically. This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale feasibility studies. Specific factors requiring evaluation include: the presence/absence of organics, concentrations of organics, present concentrations, and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures, used toxicity of microorganisms to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and the specificity of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radioactive contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL TR

Figure 2. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Indirect biological leaching BICH-I-BL	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site- and contaminant-specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Ex situ chemical treatment	Surfactant wash/Dilute nitric acid wash BICH-034	Research and development needed. Chemical washing has been an accepted method for several years. Amalgam electro-winning is not commercially available. This technology is being developed at the INEL. The technologies mentioned here have not been used in this capacity before, therefore, there will be some process modifications required.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electro-winning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.
Soil washing/leaching		Chemical washing BICH-I-CW2B	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Research to determine the ability to remove mercury from the soils is needed. Additional technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 2. Biological and chemical treatment (continued).

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 2. Biological and chemical treatment (continued).

Figure 2. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

ments	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Indirect biological leaching BICH-I-BL2	Demonstration, testing, and evaluation. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc
	Inorganic concentrations from liquids	Chemical precipitation BICH-I-CP	Research and development needed. This technology is currently available on the market. The method involves adding a chemical or chemicals to the contaminated liquid which will result in complexation or reduction and precipitation are forms of iron, sulfide, and hydroxide. This technology often requires close control of the solution pH during operation and secondary treatment to collect and dispose of the resulting sludge.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and pH levels will be required by a case by case basis. Developing a precipitation system which would be capable of targeting specific contaminants selectively rather than nonselectively would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions.
	Ex situ chemical treatment	Chemical washing (chromium) BICH-005	Research and development needed. This technology will require development. The techniques are cited in various chemistry books and are proven to work, but have not been proven to work on this type of application.	Process development is needed to demonstrate the effectiveness of these methods on the application that the INEL site requires. This demonstration phase should allow for improvement of efficiency and optimization of the amount of contamination removed.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the sludge and determine how many times the system should be cycled per amount of contamination. Process equipment for field work and scale up will also be required.
ical treatment	No biological or chemical technology identified for this site				

BIOLOGICAL AND CHEMICAL TESTS

Figure 2. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

BIOLOGICAL AND CHEMICAL

Figure 2. Biological and chemical treatment (continued).

Figure 2. Biological and chemical treatment (continued).

SOIL AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Landfarming	BICH-O-LFM	Demonstration, testing, and evaluation needed. This technology is applicable to surface soils contaminated with organics or to excavated subsurface soils spread out on the surface. The technology involves aerating the soils to a desired oxygen content, applying the appropriate moisture and nutrients (fertilizer), and monitoring the degradation of the organics. The bacteria indigenous to the soil will begin to degrade the organics as soon as the appropriate conditions are achieved. The treatment may take from 4 to 12 months to complete. In some cases, the vapors produced as a result of degradation may be considered a secondary waste stream requiring collection and treatment.	The scientific needs for this technology include the ability to achieve lower end-point concentrations, verify that the loss of organics is related to microbial degradation, and increase the rate of degradation.	Requirements to implement this technology include irrigation equipment, plowing, discing, and chiseling equipment, and possibly a better liner technology to prevent water migration away from the treatment site. If capture and treatment of off-gas streams is required, an innovative technology to accomplish that would be desirable as compared to enclosing the area with a tent or building structure.
Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Direct biological leaching	BICH-I-DL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar reactor, plus a biofilter at a lower flow rate.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition-specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include: the presence/absence of organics; concentrations of organics present; concentrations and forms of other nutrients such as nitrogen and phosphorus; direct toxicity of contaminants to microbial cultures used; toxicity of all constituents to microbes; contaminant matrix; soil buffering capacity; presence and solubility of sulfides and chlorides; and specific ability of microbes to adsorb/absorb these contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 2. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Indirect biological leaching BICH-I-BL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site soil contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bio precipitation, ion exchange, etc.
	Inorganic concentration from liquids Chemical precipitation BICH-I-CP	Research and development needed. This technology is currently available on the market. The method involves adding a chemical or chemicals to the contaminated liquid which will result in complexation or reduction and precipitation are forms of iron, sulfide, and hydroxide. This technology often requires close control of the solution pH during operation and secondary treatment to collect and dispose of the resulting sludge.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and pH levels will be required by a case by case basis. Developing a precipitation system which would be capable of targeting specific contaminants selectively rather than nonselectively would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions.
	Ex situ chemical treatment Dilute nitric acid wash - lead BICH-035	Research and development needed. Chemical washing has been an accepted method for several years. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL. The technologies mentioned here have not been used in this capacity before, therefore, there will be some process modifications required.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.
Chemical treatment	No biological or chemical technology identified at for this site

Figure 3. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

ments	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Chemical treatment	Soil washing/leaching	Chemical washing BICH-1-CW2B	Demonstration, testing, and evaluation needed This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact the technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Research to determine the ability to remove mercury from the soils is needed. Additional technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Direct biological leaching BICH-1-DL2B	Demonstration, testing, and evaluation needed This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils and for mercury, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Indirect biological leaching BICH-1-IL2B	Demonstration, testing, and evaluation needed Specific microbial cultures would be grown for collection of microbially produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation (specifically, the ability to solubilize and remove mercury). The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 3. Biological and chemical treatment - Radioactive sumps, ponds, pits, trenches, rubble piles, etc.

Figure 3. Biological and chemical treatment (continued).

TR CHEMICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
at	In situ soil remediation	Plant uptake of metals/ radionuclides BICH-I-PUC2B	Demonstration, testing, and evaluation needed This technology is limited to soils and most likely ineffec- tive for contaminated con- crete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminat- ed soil and as they grow, they uptake the contaminants from the soil through their roots and store them in vary- ing locations within the plant. Often, the plant root zone (rhizosphere) is also manipu- lated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0.12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementa- tion. Research will need to be conducted to verify that the mercury is not methy- lated and released to the atmosphere. Also, this technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irri- gation equipment, plant harvesting equipment, sub- surface monitors to verify that the irrigation is not causing contaminant migra- tion, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting con- taminated biomass.
eat	Ex situ chemical treatment	Chemical washing (cobalt, cesium, and mercury) BICH-025	Demonstration, testing, and evaluation needed The techniques are cited in various chemistry books and are proven to work, but have not been proven to work on this type of application. The crown ether process is a developing technology that can be applied, but is cur- rently very costly. The tech- nologies to be used are gen- erally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL. Ion exchange is not consid- ered to be a viable alterna- tive because it is very bulky technology. This technology also actually increases the volume of the waste.	Process development is needed to improve efficien- cy and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not avail- able commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be re- peated per amount of con- tamination. Process equip- ment for field work and scale up will also be required.
min	Organically contaminated media remediation	Slurry liquid bioremediation BICH-O-SB	Demonstration, testing, and evaluation needed This technology is applicable to retrieved fine soils, sludges, and liquids contam- inated with organics. It involves the placement of the contaminated media into a stirred-tank (as a liquid slurry) containing a chosen microbial population, additional nutri- ents and air if needed, and controlled for pH, mixing, tem- perature, and residence time. The biodegradation will result in clean sludge liquid for dis- charge.	The scientific needs for application of this technol- ogy include the bench- scale tests required to define the optimal operat- ing parameters for the spe- cific remediation need.	Hardware requirements to implement this technology are already available on the market.

BIOLOGICAL AND CHEMICAL

Figure 3. Biological and chemical treatment (continued).

Figure 3. Biological and chemical treatment (continued).

PHYSICAL CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Direct biological leaching BICH-I-DBL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost-effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Indirect biological leaching BICH-I-IBL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL AND CHEMICAL TREATMENT

Figure 3. Biological and chemical treatment (continued).

Figure 3. Biological and chemical treatment (continued).

RND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Indirect biological leaching BICH-1/IBL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost-effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.	
Ex situ chemical treatment	Chemical washing (cesium) BICH-011	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL. Ion exchange is not considered to be a viable alternative because it is very bulky technology. This technology also actually increases the volume of waste.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.
In situ soil remediation	Plant uptake of metals/radionuclides BICH-1/PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.

N

10

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH I-CW	Demonstration, testing and evaluation needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH I DBL	Demonstration, testing and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as solvents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics, presence of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Indirect biological leaching BICH I IBL	Demonstration, testing and evaluation needed. Specific microbial cultures would be grown for collection of microbially produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 3. Biological and chemical treatment (continued).

GROUNDWATER CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Ex situ chemical treatment	Chemical washing (cesium) BICH-011	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.
In situ soil remediation	Plant uptake of metals/radionuclides BICH-1-PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.
Soil washing/leaching	Chemical washing BICH-1-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 3. Biological and chemical treatment (continued).

BIOLOGICAL AND CHEMICAL TR

Figure 3. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Treatment	In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.
	Soil washing/leaching	Chemical washing BICH-I-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Direct biological leaching BICH-I-DBL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 3. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Ex situ chemical treatment	Indirect biological leaching BICH-I-IBL	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Chemical washing (cesium and strontium) BICH-012	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up will also be required.
	In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC2	Demonstration, testing, and evaluation needed. This technology is limited to soils and most likely ineffective for contaminated concrete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.

BIOLOGICAL AND CHEMICAL TR

Figure 3. Biological and chemical treatment (continued).

TRADITIONAL CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH-I-DL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation, with a similar leachate production but at a slower rate and	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition. Specifically, Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include: the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used for solubilization of contaminants, microbial buffering capacity, presence and solubility of sulfides and chlorides, and reproductive ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g. tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g. leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part time personnel would be required for this operation. For radioactive contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 3. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Ex situ chemical treatment	Indirect biological leaching BICH-1 IBL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site soil contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioprecipitation, ion exchange etc.
	Chemical washing (cesium) BICH-011	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cannot determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.
	Plant uptake of metals/radionuclides BICH-1 PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioprecipitation, ion exchange etc.

Figure 3. Biological and chemical treatment (continued).

R CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH-I-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Bioremediation BIOREMEDI	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores. One of the U.S. copper is produced biologically. This has proven to be cost effective for copper extraction, cobalt, and manganese extraction. However, it is an unproven technology on non-ore materials. This technology can be applied to a heap leach operation or a stirred tank reactor. A stirred tank reactor may require constant times that are between 4 to 6 weeks. The waste material produced will be three to seven times the volume of feed, and will require a large tank. The implementation of this process requires from the user for some data to verify that they have selected components for the contaminants. A heap leach operation is likely to require months of operation with a smaller scale production, but it is a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated contaminant specificity. Evaluations will require detailed site characterization data and bench scale and laboratory studies. Specific factors requiring evaluation include the presence of nutrients, organic concentrations, inorganic concentrations, and forms of other nutrients such as nitrogen and phosphorus. The toxicity of contaminants to the microorganisms used in the process will be a key factor in determining the applicability of the process. The user will need to provide data on the nature of the contaminants and the nature of the site conditions. The user will need to provide data on the nature of the contaminants and the nature of the site conditions. The user will need to provide data on the nature of the contaminants and the nature of the site conditions.	Hardware requirements for the stirred tank reactor (e.g. tanks, mixers, agitators, pumps, and sensors) are available and on the market. Personnel operating the unit process would require a significant amount of training and should be at a higher level. Hardware requirements for the heap leach operation (e.g. tanks, mixers, agitators, pumps, and sensors) are available and on the market. Personnel operating the unit process would require a significant amount of training and should be at a higher level. Hardware requirements for the heap leach operation (e.g. tanks, mixers, agitators, pumps, and sensors) are available and on the market. Personnel operating the unit process would require a significant amount of training and should be at a higher level.

Figure 3. Biological and chemical treatment (continued).

Indirect biological leaching
BICH-1:HL

Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site soil contaminant specific and would require evaluation on a case by case basis.

The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil-contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.

Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Ex situ chemical treatment

Chemical washing (cesium)
BICH-011

Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.

Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.

Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.

Ex situ chemical treatment

Ex situ chemical treatment

Sodium bicarbonate washing
BICH-023

Demonstration, testing, and evaluation needed. This is a developed technology that can be applied. Research may be required to optimize the process.

No science and technology needs identified.

Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 3. Biological and chemical treatment (continued).

Figure 3. Biological and chemical treatment (continued).

Ex situ chemical treatment

Chemical washing (cobalt and cesium)

BICH-009

Research and development needed.

This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required.

Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.

Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved.

Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.

Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.

Chemical treatment

Soil washing/leaching

Chemical washing

BICH-I-CW

Research and development needed.

This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.

Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.

Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation.

Direct biological leaching

BICH-I DBL

Demonstration, testing, and evaluation needed.

This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.

Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics, presence/absence of nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-contaminants to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.

Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 3. Biological and chemical treatment (continued).

PHYSICAL AND CHEMICAL TREATMENT

ents	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Indirect biological leaching BICH-I-BIL	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Ex situ chemical treatment	Chemical washing (cobalt, cesium, chromium, and mercury) BICH-026	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.

Figure 3. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Direct biological leaching BICH-I-DBL2		Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures, used toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 3. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Indirect biological leaching BICH-I-IBL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Organically contaminated soil remediation	Slurry/liquid bioremediation BICH-O-SB2	Demonstration, testing, and evaluation needed. This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred-tank (as a liquid/slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge/liquid for discharge.	The scientific needs for application of this technology include the bench-scale tests required to define the optimal operating parameters for the specific remediation need. Additionally, the impacts of lead and other inorganic co-contaminants on this process will need to be assessed.	Hardware requirements to implement this technology are already available on the market. This technology will need to be coupled with other unit processes targeting the inorganic contaminant fraction.
Ex situ chemical treatment	Hot nitrogen stripping BICH-O-031	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are documented to be successful in various text books, but have not been used for the purpose of waste reduction. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required.	Process development may be required to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up will also be required.

Figure 4. Biological and chemical treatment. Nonradioactive spill areas, spill migrations, and unconfined disposal sites.

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 4. Biological and chemical treatment (continued).

11

C AND CHEMICAL TREATMENT

ements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Indirect biological leaching BICH I-BL	Demonstration, testing, and evaluation needed Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
ically rem	Organically contaminated soil remediation	Slurry liquid bioremediation BICH O-SB2	Demonstration, testing, and evaluation needed This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred tank (as a liquid slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge liquid for discharge.	The scientific needs for application of this technology include the bench-scale tests required to define the optimal operating parameters for the specific remediation need. Additionally, the impacts of lead and other inorganic co-contaminants on this process will need to be assessed.	Hardware requirements to implement this technology are already available on the market. This technology will need to be coupled with other unit processes targeting the inorganic contaminant fraction.
u ch	Ex situ chemical treatment	Surfactant wash/Dilute nitric acid wash BICH-034	Research and development needed. Chemical washing has been an accepted method for several years. Amalgam electro-winning is not commercially available. This technology is being developed at the INEL. The technologies mentioned here have not been used in this capacity before, therefore, there will be some process modifications required.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electro-winning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for field work and scale up, will also be required.
ically rem	Organically contaminated soil remediation	Slurry liquid bioremediation BICH O-SB	Demonstration, testing, and evaluation needed This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred tank (as a liquid slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge liquid for discharge.	The scientific needs for application of this technology include the bench scale tests required to define the optimal operating parameters for the specific remediation need.	Hardware requirements to implement this technology are already available on the market.

BIOLOGICAL AND CHEMICAL TR

Figure 4. Biological and chemical treatment (continued).

HEMICAL TREATMENT

Figure 4. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Figure 4. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Landfarming	BICH-O-LFM	Demonstration, testing, and evaluation. This technology is applicable to surface soils contaminated with organics or to excavated subsurface soils spread out on the surface. The technology involves aerating the soils to a desired oxygen content, applying the appropriate moisture and nutrients (fertilizer), and monitoring the degradation of the organics. The bacteria indigenous to the soil will begin to degrade the organics as soon as the appropriate conditions are achieved. The treatment may take from 4 to 12 months to complete. In some cases, the vapors produced as a result of degradation may be considered a secondary waste stream requiring collection and treatment.	The scientific needs for this technology include the ability to achieve lower end-point concentrations, verify that the loss of organics is related to microbial degradation, and increase the rate of degradation.	Requirements to implement this technology include irrigation equipment, plowing, discing, and chiseling equipment, and possibly a better liner technology to prevent water migration away from the treatment site. If capture and treatment of off-gas streams is required, an innovative technology to accomplish that would be desirable as compared to enclosing the area with a tent or building structure.
Ex situ chemical treatment	Surfactant washing BICH-024	Research and development needed. This is a developing technology that can be applied, but is currently very costly. Research may be required to optimize the biodegradation process.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Process equipment for fieldwork and scale up, will also be required.
Organically contaminated soil remediation	Slurry/liquid bioremediation BICH-O-SB	Demonstration, testing, and evaluation. This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred tank (as a liquid/slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge/liquid for discharge.	The scientific needs for application of this technology include the bench-scale tests required to define the optimal operating parameters for the specific remediation need. Additionally, the impacts of lead and other inorganic co-contaminants on this process will need to be assessed.	Hardware requirements to implement this technology are already available on the market. This technology will need to be coupled with other unit processes targeting the inorganic contaminant fraction.
	Subsurface bioremediation BICH-O-SSB	Demonstration, testing, and evaluation. This technology is applicable to subsurface soils contaminated with organics. It involves the addition/injection of nutrients, organics (for certain halocarbon contaminants), air, and possibly microorganisms to the contaminated area to stimulate natural biodegradation in the region of the contamination. The biodegradation will result in clean soil in a time period of 12 to 36 months.	The scientific needs for this technology include the ability to achieve lower end point concentrations, verify that the loss of organics is related to microbial degradation, and increase the rate of degradation. Advanced subsurface delivery systems are also needed. The single most critical need for subsurface biodegradation is the ability to conduct better modeling of the subsurface being remediated. This would result in information which could be used to optimize the delivery systems and define the requirements for the additives.	Requirements to implement this technology include advanced drilling techniques, pumps, and sensors to monitor degradation and additive permeation.

Figure 5. Biological and chemical treatment. Radioactive spill areas, spill migrations, and unconfined disposal sites.

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

BIOLOGICAL AND CHEMICAL TR

Figure 5. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Indirect biological leaching BICH-I-BL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Ex situ chemical treatment	Cold dilute potassium hydroxide washing BICH-032	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development may be required to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up will also be required.
In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC	Demonstration, testing, and evaluation needed. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.

BIOLOGICAL AND CHEMICAL AND CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

TRADITIONAL CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH-I-DBL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Indirect biological leaching BICH-II-DBL2	Demonstration, testing, and evaluation. Specific micro-organisms would be grown for solubilization of the typically predicted toxic organic, inorganic, and/or other chemicals. These products would be added to the contaminated soil. This technology is most likely not applicable to contaminated concrete or debris in slurry phase reactors due to the need to separate the micro-organisms and/or nutrients from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site and contaminant specific, and would require evaluation on a case by case basis.	The applicability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each of the soil and contaminant combinations prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology cannot remove all of the contaminants from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a technician level. For radionuclide contaminated soils, containment needs would require evaluation. The type of implementation for the treatment coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 5. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Ex situ chemical treatment	Chemical washing (cesium and strontium) BICH-012	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up will also be required.
Soil washing/leaching	Chemical washing BICH-1-CW2B	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Research to determine the ability to remove mercury from the soils is needed. Additional technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH-1-DBL2B	Demonstration, testing and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils and for mercury and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 5. Biological and chemical treatment (continued).

ID CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Elements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Direct biological leaching BICH-I-DBL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-contaminants to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radioactive contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Indirect biological leaching BICH-I-IBL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially produced acids, organic or inorganic, and of other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris in slurry phase mixed reactors) to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radioactive contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

Figure 5. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Ex situ chemical treatment	Direct biological leaching BICH-I-DBL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost-effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Indirect biological leaching BICH-I-IBL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site soil contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Chemical washing (cesium) BICH-011	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.

Figure 5. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
→ In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC2	Demonstration, testing, and evaluation needed. This technology is limited to soils and most likely ineffective for contaminated concrete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.
→ Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH-I-DBL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 5. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

BIOLOGICAL AND CHEMICAL TR

Figure 5. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Direct biological leaching BICH-I-DBL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost-effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Indirect biological leaching BICH-I-IBL2	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil-contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Ex situ chemical treatment	Chemical washing (cesium) BICH-011	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.

Figure 5. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

ments	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Chemical treatment	In situ soil remediation	Plant uptake of metals/radionuclides BICH-I-PUC2	Demonstration, testing, and evaluation needed. This technology is limited to soils and most likely ineffective for contaminated concrete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass
	Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 5. Biological and chemical treatment (continued).

TR CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	<p>Direct biological leaching BICH I-DBL2</p> <p>Indirect biological leaching BICH I-IBL2</p>	<p>Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low-grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost-effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore-like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry-phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.</p> <p>Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site soil contaminant specific and would require evaluation on a case by case basis.</p>	<p>Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics present, concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.</p> <p>The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.</p>	<p>Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipe) are also available and on the market. Only part-time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.</p> <p>Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.</p>
Ex situ chemical treatment	Chemical washing (cesium) BICH-011	<p>Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.</p>	<p>Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.</p>	<p>Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.</p>

Figure 5. Biological and chemical treatment (continued).

CAND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs	
In situ soil remediation	Plant uptake of metals/radionuclides BICH I-PUC	Demonstration, testing, and evaluation needed. This technology is limited to soils and most likely ineffective for contaminated concrete and debris. Specific plants are chosen based on environmental conditions and the contaminant requiring remediation. The plants are cultivated on the contaminated soil and as they grow, they uptake the contaminants from the soil through their roots and store them in varying locations within the plant. Often, the plant root zone (rhizosphere) is also manipulated such that special fungi (mycorrhizae) can assist the plants with the contaminant uptake. The plants are then harvested and further treated, and over a period of years (5 to 15) the surface soils (0-12 inches) are predominantly cleaned. This technology has been demonstrated in Europe with a number of heavy metals.	The specific plant(s) to be used at each site and for each contaminant would require evaluation prior to technology implementation. This technology could have a much broader applicability if the root zones could be encouraged to go deeper.	Requirements to implement this technology include irrigation equipment, plant harvesting equipment, subsurface monitors to verify that the irrigation is not causing contaminant migration, secondary treatment for the harvested plants/plant parts, and for radionuclide contamination, a containment facility to prevent the plants from being foraged by insects, birds, and other animals. This technology will need to be coupled with secondary treatment technologies to deal with the resulting contaminated biomass.	
	Soil washing/leaching	Chemical washing BICH I-CW	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
	Direct biological leaching BICH I DBL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores (30% of the U.S. copper is produced biologically). This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils, and is most likely not applicable to concrete and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily contain the suspension of spent microbes from the reactor since it is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, concentrations of organics, presence of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures, used toxicity of co-constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

Figure 5. Biological and chemical treatment (continued).

ND CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing/leaching	Chemical washing BICH-I-CW2	Research and development needed. This technology is currently available on the market for treatment of soil, but not for concrete and other debris. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Direct biological leaching BICH-I-DBL2	Direct biological leaching BICH-I-DBL2	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores. 30% of the U.S. copper is produced biologically. This has proven to be cost effective for copper, uranium, cobalt, and manganese extraction. However, it is an unproven technology on non ore like soils, and is most likely not applicable to clays, silts, and other debris. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be three to seven times the volume of soil, and will necessarily require the separation of spent microorganisms from the leachate for reuse or likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, present concentrations and forms of other nutrients such as nitrogens and phosphorus, direct toxicity of contaminants to the microbial cultures used, diversity of microorganisms to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of the reactor to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g. tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a technician level. Hardware requirements for heap leaching (e.g. leach pads, liners, pumps, sprinkler pipes) are also available and on the market. Only part time personnel would be required for the operation. For natural leachate contaminated soils, contaminant trends would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL TI

Figure 5. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Indirect biological leaching BICH-I-BL2		Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially-produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil (this technology is most likely not applicable to contaminated concrete or debris) in slurry-phase mixed reactors to leach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined in bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology can not remove all of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
Ex situ chemical treatment	Chemical washing (cesium) BICH-011	Research and development needed. This is a developing technology that can be applied, but is currently very costly. The technologies to be used are generally very inefficient. Crown ethers are currently available only in small quantities. Usually the research facilities that are working with these crown ethers make the small amounts of the particular crown ether that is required. Amalgam electrowinning is not commercially available. This technology is being developed at the INEL.	Process development is needed to improve efficiency and increase the extent of contaminant removal which can be achieved. Development of amalgam electrowinning will be required. As stated before this technology is not available commercially.	Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and cement and determine how many times the system should be repeated per amount of contamination. Research and development of mass production of the crown ethers will be required to produce larger quantities than are currently being produced. Process equipment for field work and scale up, will also be required.

atment → No biological or chemical technology identified for this site.

Figure 5. Biological and chemical treatment (continued).

BIOLOGICAL AND CHEMICAL TR

Figure 5. Biological and chemical treatment (continued).

CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

CAL AND CHEMICAL TREATMENT

Elements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
ash	Soil washing/leaching	Chemical washing BICH-I-CW	Research and development needed. This technology is currently available on the market. The method involves agitating the soil in a slurry tank containing various combinations and concentrations of water, inorganic salts, mineral acids, complexing agents (generally proprietary), and often, specific surfactants, detergents, and heat. This procedure only cleans a fraction of the contaminated soil based on soil particle size and how the contaminants are bound to the soil particles. Often, different soil size fractions have different chemistry and therefore bind contaminants differently. Due to this fact, this technology often requires a coupled treatment to separate the clean soil from the contaminated soil by sizing methods. The leachate produced from this technology also requires treatment.	Technology development activities are needed to increase the extent of contaminant removal which can be achieved. Specific chemicals and washing techniques will be required on a case by case basis. Developing a washing system which would be efficient for application to clays, silts, and fines would greatly enhance this technology.	Hardware requirements for this technology are available and on the market. Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions.
		Direct biological leaching BICH-I-DL	Demonstration, testing, and evaluation needed. This technology is used currently in the mining industry to solubilize metals from low grade ores. 80% of the U.S. copper is produced biologically. This has proven to be cost effective for copper, and ruthenium, and manganese extraction. However, it is an unproven technology on non ore like soils. This technology can be applied as a heap leach operation or in a stirred tank reactor. A slurry phase reactor may require contact times that range from 4 to 48 hours. The leachate produced will be twice to seven times the volume of soil, and will necessarily contain the supernatant of the spent microbes from the reactor. It is likely that they have acted as sorbents for the contaminants. A heap leach operation is likely to require months of operation with a similar leachate production, but at a lower total cost.	Technology applicability will require evaluation on a site by site and case by case basis due to anticipated condition specificity. Evaluations will require detailed site characterization data and bench scale treatability studies. Specific factors requiring evaluation include the presence/absence of organics, present concentrations and forms of other nutrients such as nitrogen and phosphorus, direct toxicity of contaminants to microbial cultures used, toxicity of co constituents to microbes, contaminant matrix, soil buffering capacity, presence and solubility of sulfides and chlorides, and specific ability of microbes to adsorb/absorb the contaminants.	Hardware requirements for the stirred tank reactor (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating this unit process would require a small amount of training and should be at a "technician" level. Hardware requirements for heap leaching (e.g., leach pads, liners, pumps, sprinkler, pipes) are also available and on the market. Only part time personnel would be required for this operation. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.
		Indirect biological leaching BICH-I-DL	Demonstration, testing, and evaluation needed. Specific microbial cultures would be grown for collection of microbially produced acids (organic or inorganic) and/or other chelators. These products would be added to the contaminated soil in slurry phase mixed reactors to reach the metals and/or radionuclides from the soil. The resulting leachate would be two to five times greater volume than the contaminated soil. The leachate would be collected and further treated to concentrate the contaminants as desired. This leaching process is relatively rapid and would require a slurry residence time of between ten minutes and two hours. The applicability of this technology is very likely site/soil/contaminant specific and would require evaluation on a case by case basis.	The amenability of each soil and contaminant combination to this type of leaching is different and would require evaluation. The exact treatment process parameters (e.g., pH, temperature, pulp density) would need to be defined as bench scale treatability studies for each different soil/contaminant condition, prior to technology implementation. The presence of large concentrations of organics in the soil may be detrimental to this type of leaching. This technology is not removal of the contamination from the soil, but can be expected to remove as much as any other known technology.	Hardware requirements (e.g., tanks, mixers, pH meters, pumps, augers) are available and on the market. Personnel operating the unit process would require a small amount of training and should be at a "technician" level. For radionuclide contaminated soils, containment needs would require evaluation. Effective implementation also requires coupling with secondary treatment such as chemical precipitation, bioaccumulation, bioprecipitation, ion exchange, etc.

BIOLOGICAL AND CHEMICAL TREATMENT

Figure 5. Biological and chemical treatment (continued).

Figure 6. Biological and chemical treatment. Injection wells, groundwater, and associated plumes.

ND CHEMICAL TREATMENT

ents	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
------	--------------	--------------	--------	------------------------------	----------------------

al treatment → No biological or chemical technology identified for this site

Figure 7. Biological and chemical treatment. Unexploded naval ordnance.

TRADITIONAL CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

Figure 8. Biological and chemical treatment. Landfills.

ND CHEMICAL TREATMENT

ents	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
------	--------------	--------------	--------	------------------------------	----------------------

al treatment → Organically contaminated soil remediation → Slurry/liquid bioremediation BICH-O-SB → Demonstration, testing, and evaluation needed. This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred-tank (as a liquid/slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge/liquid for discharge. → The scientific needs for application of this technology include the bench-scale tests required to define the optimal operating parameters for the specific remediation need. → Hardware requirements to implement this technology are already available on the market.

al treatment → Organically contaminated soil remediation → Slurry/liquid bioremediation BICH-O-SB2 → Demonstration, testing, and evaluation needed. This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred-tank (as a liquid/slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge/liquid for discharge. → The scientific needs for application of this technology include the bench-scale tests required to define the optimal operating parameters for the specific remediation need. Additionally, the impacts of lead and other inorganic co-contaminants on this process will need to be assessed. → Hardware requirements to implement this technology are already available on the market. This technology will need to be coupled with other unit processes targeting the inorganic contaminant fraction.

→ Ex situ chemical treatment → Chemical washing (chromium, mercury, and beryllium) BICH-013 → Research and development needed. This technology will require development. The techniques are cited in various chemistry books and are proven to work, but have not been proven to work on this type of application. → Process development is needed to demonstrate the effectiveness of these methods on the application that the INEL site requires. This demonstration phase should allow for improvement of efficiency and optimization of the amount of contamination removed. → Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the sludge and determine how many times the system should be cycled per amount of contamination. Process equipment for field work and scale up, will also be required.

nical treatment → Ex situ chemical treatment → Chemical washing (chromium, mercury, and beryllium) BICH-014 → Research and development needed. This technology will require development. The techniques are cited in various chemistry books and are proven to work, but have not been proven to work on this type of application. → Process development is needed to demonstrate the effectiveness of these methods on the application that the INEL site requires. This demonstration phase should allow for improvement of efficiency and optimization of the amount of contamination removed. → Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the soil and determine how many times the system should be cycled per amount of contamination. Process equipment for field work and scale up, will also be required.

Figure 8. Biological and chemical treatment (continued).

AND CHEMICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
<p>chemical treatment → No biological or chemical technology available for this site.</p>				
<p>chemical treatment → Organically contaminated soil remediation</p>	<p>Slurry/liquid bioremediation BICH-O-SB</p>	<p>Demonstration, testing, and evaluation needed. This technology is applicable to retrieved fine soils, sludges, and liquids contaminated with organics. It involves the placement of the contaminated media into a stirred-tank (as a liquid/slurry) containing a chosen microbial population, additional nutrients and air if needed, and controlled for pH, mixing, temperature, and residence time. The biodegradation will result in clean sludge/liquid for discharge.</p>	<p>The scientific needs for application of this technology include the bench-scale tests required to define the optimal operating parameters for the specific remediation need.</p>	<p>Hardware requirements to implement this technology are already available on the market.</p>
<p>chemical treatment → Ex situ chemical treatment</p>	<p>Chemical washing (chromium, mercury, and beryllium) BICH-013</p>	<p>Research and development needed. This technology will require development. The techniques are cited in various chemistry books and are proven to work, but have not been proven to work on this type of application.</p>	<p>Process development is needed to demonstrate the effectiveness of these methods on the application that the INEL site requires. This demonstration phase should allow for improvement of efficiency and optimization of the amount of contamination removed.</p>	<p>Implementation requires good characterization data and bench scale testing to optimize the process for the given conditions. The bench scale testing will also determine the cleanliness of the sludge and determine how many times the system should be cycled per amount of contamination. Process equipment for field work and scale up, will also be required.</p>

Thermal and Physical

The thermal and physical treatment section of this TLD addresses technologies for p
Options for thermal treatment are divided into four processes, including incineration, vitrification
four processes are shown below.

1. Incineration
 - a. Controlled air
 - b. Rotary kiln
 - c.. Liquid injection
 - d. Industrial boiler
 - e. Water based reactive plasma

2. Vitrification
 - a. Ex situ vitrification

3. Thermal Desorption
 - a. Rotary kiln
 - (1) direct
 - (2) indirect
 - b. Externally fired roaster
 - c. Indirect heat screw conveyor
 - d. Anaerobic thermal processor

4. Thermal Degradation
 - a. Wet air oxidation
 - b. Supercritical w

Physical processes are sub
which are shown in the following list

1. Solidification/Stabilization
 - a. Cementitious
 - b. Polymer
 - c. In situ auger in
2. Vapor Vacuum Extrac
3. Screening and Sorting
4. Blasting Methods
 - a. CO₂ blasting

Physical Treatment

technologies for processing wastes generated during cleanup of INEL contaminated sites. Generation, vitrification, thermal desorption, and thermal degradation. Subcategories of these

Thermal Degradation

Wet air oxidation

Supercritical water oxidation

b. Water crystal

c. Sand blasting

5. Amalgamation

6. Centrifugal Separations

7. Evaporation

8. Soil washing

9. Size reduction

a. Crusher plant

Processes are subdivided into 9 processes, shown in the following list.

Stabilization/Stabilization

Cementitious

Polymer

In situ auger injection

Vacuum Extraction, In situ

Grinding and Sorting

Grinding Methods

CO₂ blasting

Figure 1. Thermal and physical treatment. Radioactive underground storage tanks, aboveground storage tanks, and associated soils.

PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs	
Blasting method	CO ₂ blasting	THRM/PHYS PB-01	Accepted. Technology has been in development over the last ten years and has been bench-scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose, surface contamination, and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 lbs./hr. Basically, a line of sight cleaning method, limited effect around corners, or in deep channels. No secondary wastes are generated. Not effective on concrete.	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also, the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000, and operating costs are estimated to range from \$15/hr., for industrial cleaning applications, to \$300/hr., for radioactive contamination removal. Equipment requirements include a pelletizer, to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. Also, an enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.	
		Sand blasting	THRM/PHYS PB-03	Accepted. A long standing, successful, and well understood technology. Generates secondary waste stream.	Technology has no science or technology needs for this application.	Normal implementation needs. Secondary waste stream from blasting may require further treatment prior to disposal.
		Water crystal (ice) blasting	THRM/PHYS PB-02	Accepted. Technology has been in development for several years and has been shown to be very effective at removing both loose and fixed contamination.	Technology has no science or technology needs for this application.	A high efficiency blast nozzle is necessary to transfer energy from blast air to ice particles.
	Soil washing	Soil washing	THRM/PHYS PSW-01	Research and development needed. Soil washing is a water based, volumetric reduction/waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume.	Technology requires further development for radionuclides. Technology is most effective as a waste minimization/volume reduction process. For the process to be economically feasible, the contaminated material must consist of not more than 40% passing 63 microns. The contaminated soil should contain less than 20% by volume of solid organic material. Complex waste mixtures, such as metals with organics, make washing fluid formulation difficult.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
Thermal degradation	Supercritical water oxidation	THRM/PHYS TO-02	Research and development needed. The INEL is preparing for a series of pilot-scale tests on surrogate mixed wastes. The technology shows strong promise for treatment of oxidizable hazardous wastes, with demonstrated destruction efficiencies as high as 99.9999%. Can be operated in a closed process batch cycle. Research work is currently being funded through the INEL for advancement of this technology.	Specific wastestreams must be pilot tested. Equipment corrosion problems must be solved. A better theoretical base must be established for chemical reactions in supercritical water.	Requires high pressure system hardware. Stabilization of Radionuclides and RCRA Heavy metals will be required once organics have been destroyed.	

associated soils.

Figure 1. Thermal and physical treatment (continued).

IONIC AND PHYSICAL TREATMENT

THERMAL AND PHYSICAL T

Figure 1. Thermal and physical treatment (continued).

PHYSICAL TREATMENT

Figure 1. Thermal and physical treatment (continued).

IC L AND PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Ex situ vitrification	Minimum additive waste stabilization (MAWS) THRM/PHYS PF-02	Research and development needed. Initial demonstration at Fernald is a low-temperature joule melter which incorporates soil washing and ion exchange water treatment. It is being demonstrated to stabilize contaminated sludges (contaminated with magnesium fluoride, low-level organics, toxic metals, uranium) soils, and fly ash into one waste form. The technology system is essentially closed-loop with secondary wastes produced from offgas scrubbing being recycled back to the melter. Waste forms pass EPA TCLP leachability tests.	There is a need to develop additional MAWS technologies and apply them to DOE complex needs. This will be done by choosing wastes that are site specific, but also relevant to the needs of the complex. Additional work will be done in FY-94 to identify a compositional window of waste streams/constituents that will produce a quality final waste form using the MAWS concept.	Actual waste streams from the sites require testing initially to determine feasibility of producing a quality waste form as was done for Fernald wastes.
Solidification/stabilization	Cementitious THRM/PHYS PSS-01	Accepted Cementitious treatment using Portland Cement has been used extensively for treatment of LLW in the nuclear power industry. It has also been used frequently for treatment of RCRA hazardous waste where S.S. has been determined Best Demonstrated Available Technology (BDAT). May not properly treat for mercury disposal.	Technology has no science or technology development needs for this application.	Normal implementation needs. Treatment costs are low but will be strongly dependent on secondary treatment options which are waste specific. Elemental Mercury generated may require Amalgamation prior to disposal.
Evaporation	Evaporation THRM/PHYS PE-01	Accepted Many types of variations of evaporators are available. The most common designs used for radioactive liquid wastes include pot kettle or pan evaporators, natural circulation systems, and forced circulation systems. They are operated as batch, semi batch, and continuous processes. The complexity of the design is dependent on the type and degree of separation required.	For new applications the degree of separation would have to be investigated. Foaming and scaling problems are common, requiring special measures for each application.	Field tests would be required to establish separation efficiency and potential operational problems. Energy requirements are high.
Soil washing	Soil washing THRM/PHYS PSW-01	Research and development for soils at INEL containing Sr90 and Cs137. Soil washing is a water based volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, and from clay soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.

Figure 1. Thermal and physical treatment (continued).

AND PHYSICAL TREATMENT

Figure 1. Thermal and physical treatment (continued).

IO AND PHYSICAL TREATMENT

Figure 1. Thermal and physical treatment (continued).

PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Thermal desorption	Externally fired roaster THRM/PHYS TD-04	Demonstration, testing, and evaluation needed. Accepted for nonradioactive contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9.	Design and demonstration of mixed waste feed systems and treated waste handling systems. Desorption characteristics for Mercuric Nitrate must be identified.	Normal implementation needs. Treatment costs should be fairly low, but will be strongly dependent on secondary treatment options, which are waste specific. Elemental Mercury generated may require Amalgamation prior to disposal.
	Rotary kiln - direct THRM/PHYS TD-02	Accepted, for nonradioactive contaminated hazardous waste and has been used at several EPA Superfund sites. The process is most amenable to hydrocarbon contaminated soils and sludges.	Development Test the equipment with surrogate hazardous and radioactive materials to ensure that seals can adequately contain hazardous and radioactive material. Development feed system for radioactive waste. Waste characterization in support of production. Secondary waste minimization. Maintenance. Scrubber technology.	Normal implementation needs. Treatment costs should be fairly low, depending on the secondary offgas cleanup systems required. Wide Beach Superfund Site costs were approximately \$185.00/ton.
Soil washing	Soil washing THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr ⁹⁰ and Cs ¹³⁷ . Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
Amalgamation	Amalgamation THRM/PHYS PA-01	Research and development needed. The INEL has treated mercury in a bench-scale mode to pass TCLP. A pilot-scale unit will be permitted in one to two years. There are no commercial units presently available to treat large quantities of elemental mercury.	The pilot-scale unit will require some testing since the equipment will differ slightly from the bench-scale equipment (INEL). It still needs to be determined if some DOE or comparable facility has developed this system at pilot level.	The equipment for performing this amalgamation is inexpensive (paint shaker). All debris or materials should be separated away from the mercury prior to amalgamation. If not much elemental mercury is present (<1 liter), bench-scale procedures should be adequate.
Ex situ vitrification	Minimum additive waste stabilization (MAWS) THRM/PHYS PF-02	Research and development needed. Initial demonstration at Fernald is a low-temperature joule melter which incorporates soil washing and ion exchange water treatment. It is being demonstrated to stabilize contaminated sludges (contaminated with magnesium fluoride, low-level organics, toxic metals, uranium) soils, and fly ash into one waste form. The technology system is essentially closed-loop with secondary wastes produced from offgas scrubbing being recycled back to the melter. Waste forms pass EPA TCLP leachability tests	There is a need to develop additional MAWS technologies and apply them to DOE complex needs. This will be done by choosing wastes that are suitable to this process, but also relevant to the needs of the complex. Additional work will be done in FY-94 to identify a compositional window of waste streams/constituents that will produce a quality final waste form using the MAWS concept.	Actual waste streams from the sites require testing initially to determine feasibility of producing a quality waste form as was done for Fernald wastes.

Figure 1. Thermal and physical treatment (continued).

THERMAL AND PHYSICAL TREATMENT

Figure 1. Thermal and physical treatment (continued).

ND PHYSICAL TREATMENT

Alternative	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
-------------	--------------	--------------	--------	------------------------------	----------------------

THERMAL AND PHYSIC

Figure 2. Thermal and physical treatment. Nonradioactive sumps, ponds, pits, trenches, rubble piles, etc.

AND PHYSICAL TREATMENT

Figure 2. Thermal and physical treatment (continued).

PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing	Soil washing THRM PHYS PSW 01	Accepted Soil washing is a water based, volumetric reduction waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is widely used in Europe. Typical hazardous contaminants which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, and pesticides.	Technology requires no scientific or technological development for this application.	Normal implementation needs. Residuals will require further treatment or disposal in a RCRA subtitle C facility.
Thermal desorption	External fired roaster THRM PHYS TD 04	Accepted. for nonradioactive contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9.	Technology requires no scientific or technological development for this application.	Normal implementation needs. Treatment costs are low. Lead may require additional treatment. If glass still present, needs to be broken.
	Indirect heat screw conveyor THRM PHYS TD 06	Accepted. Commercially available for non-radioactive treatment of volatile and semivolatile contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.
	Anaerobic thermal processor THRM PHYS TD 07	Accepted. Commercially available for non-radioactive treatment of volatile, semi-volatile and PCB contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.
Stabilization	Cementitious THRM PHYS PSS 01	Accepted. Cementitious treatment has been used frequently used for treatment of RCRA hazardous waste where treatment standard has been determined. best demonstrates available technology (BDAT). Does not address heavy hydrocarbons.	Technology requires no scientific or technological development for this application.	Normal implementation needs. Will also require treatment for heavy hydrocarbons.
Soil washing	Soil washing THRM PHYS PSW 01	Accepted. Soil washing is a water based, volumetric reduction waste minimization process whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is widely used in Europe. Typical hazardous contaminants which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, and pesticides.	Technology requires no scientific or technological development for this application.	Normal implementation needs. Residuals will require further treatment or disposal in a RCRA subtitle C facility.
Thermal desorption	External Fired Roaster THRM PHYS TD 04	Accepted. for nonradioactive contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9.	Technology requires no scientific or technological development for this application.	Normal implementation needs. Treatment costs are low. Lead may require additional treatment. If glass still present, needs to be broken.
	Indirect heat screw conveyor THRM PHYS TD 06	Accepted. Commercially available for non-radioactive treatment of volatile and semivolatile contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.
	Anaerobic thermal processor THRM PHYS TD 07	Accepted. Commercially available for non-radioactive treatment of volatile, semi-volatile and PCB contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.

Figure 2. Thermal and physical treatment (continued).

THERMAL AND PHYSICAL AND PHYSICAL TREATMENT

Figure 2. Thermal and physical treatment (continued).

Figure 2. Thermal and physical treatment (continued).

ation

ng

ation

THERMAL AND PHYSICAL TREATMENT

Figure 3. Thermal and physical treatment. Radioactive sumps, ponds, pits, trenches, rubble piles, etc.

PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Size reduction	Crusher plant THRM/PHYS CR-001	Accepted This technology is readily available and widely used in size reduction of concrete and asphalt with low levels of radioactive contamination	None	A crusher plant would be used to size reduce materials that would otherwise be too massive.
Soil washing	Soil washing THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr^{90} and Cs^{137} . Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
Solidification/stabilization	External fired roaster THRM/PHYS TD-04	Demonstration, testing, and evaluation needed Accepted for non-radioactive contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9	Design and demonstration of mixed waste feed systems and treated waste handling systems. Desorption characteristics for Mercuric Nitrate must be identified	Normal implementation needs. Treatment costs should be fairly low, but will be strongly dependent on secondary treatment options which are waste specific. Elemental Mercury generated may require Amalgamation prior to disposal.
	In situ auger injection THRM/PHYS PSS-03	Accepted In Situ Fixation Co. has dual auger equipment to inject and mix without excavation. They also have a twin, 5 ft auger system powered and moved by a standard back hoe. Auger drills into soil, and a controlled nozzle system. Millgard Environmental Corp. has the MecTool system which has been approved for solidification of 30,000 cubic yards in India, and a pilot test underway in a Canadian province.	Debris which is buried underground, such as tree stumps, mechanical equipment, large concrete slabs, etc., will cause problems.	Needs demonstration on trial site. Mercury needs to be removed prior to stabilization.
Amalgamation	Amalgamation THRM/PHYS PA-01	Demonstration, testing, and evaluation needed The INEL has treated mercury in a bench scale mode to pass TCLP. A pilot-scale unit will be permitted in one to two years. There are no commercial units presently available to treat large quantities of elemental mercury.	The pilot scale unit will require some testing since the equipment will differ slightly from the bench scale equipment (INEL). It still needs to be determined if some DOE or comparable facility has developed this system at pilot level.	The equipment for performing this amalgamation is expensive (pilot shaker). All debris or materials should be separated away from the mercury prior to amalgamation. If not much elemental mercury is present (< 1 liter), bench scale procedures should be adequate.

THERMAL AND PHYSICAL AND PHYSICAL TREATMENT

Figure 3. Thermal and physical treatment (continued).

THERMAL AND PHYSICAL T

Figure 3. Thermal and physical treatment (continued).

TECHNOLOGICAL AND PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Further characteristic data is required to assess technologies for this site					
Blasting method	CO ₂ blasting THRM PHYS PB 01	Accepted Technology has been in development over the last ten years and has been bench-scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose, surface contamination, and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 lbs. hr. Basically a line of sight cleaning method, limited effect around corners, or in deep channels. No secondary wastes are generated. Not effective on concrete.	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also, the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000, and operating costs are estimated to range from \$15/hr. for industrial cleaning applications, to \$300/hr. for radioactive contamination removal. Equipment requirements include a pelletizer, to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. Also, an enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.	
	Sand blasting THRM PHYS PB 03	Accepted A long standing, successful, and well understood technology. Generates secondary waste stream.	Technology has no science or technology needs for this application.	Normal implementation needs. Secondary waste stream from blasting may require further treatment prior to disposal.	
	Water crystal (ice) blasting THRM PHYS PB 02	Accepted Technology has been in development for several years and has been shown to be very effective at removing both loose and fixed contamination.	Technology has no science or technology needs for this application.	A high efficiency blast nozzle is necessary to transfer energy from blast air to ice particles.	
Soil washing	Soil washing THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr ⁹⁰ and Cs ¹³⁷ . Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.	
Thermal desorption	Indirect heat screw conveyor THRM PHYS TD 06	Accepted Commercially available for non-radioactive treatment of volatile and semivolatile contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.	
	Anaerobic thermal processor THRM PHYS TD 07	Accepted Commercially available for non-radioactive treatment of volatile, semi-volatile and PCB contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.

Figure 3. Thermal and physical treatment (continued).

IC AND PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
<p>Soil washing</p> <p>Soil washing</p> <p>Soil washing</p>	<p>THRM/PHYS PSW-01</p> <p>THRM/PHYS PSW-01</p> <p>THRM/PHYS PSW-01</p>	<p>Research and development needed for soils at INEL containing Sr⁹⁰ and Cs¹³⁷. Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.</p> <p>Research and development needed for soils at INEL containing Sr⁹⁰ and Cs¹³⁷. Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.</p> <p>Research and development needed for soils at INEL containing Sr⁹⁰ and Cs¹³⁷. Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.</p>	<p>Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.</p> <p>Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.</p> <p>Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.</p>	<p>The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.</p> <p>The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.</p> <p>The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.</p>

THERMAL AND PHYSICAL T

Figure 3. Thermal and physical treatment (continued).

D PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
--------------	--------------	--------	------------------------------	----------------------

Figure 3. Thermal and physical treatment (continued).

THERMAL AND PHYSICAL T

Figure 3. Thermal and physical treatment (continued).

PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing	Soil washing	THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr90 and Cs137. Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
Evaporation	Evaporation	THRM/PHYS PE-01	Accepted. Many types of variations of evaporators are available. The most common designs used for radioactive liquid wastes include pot, kettle, or pan evaporators, natural circulation systems, and forced circulation systems. They are operated as batch, semi batch, and continuous processes. The complexity of the design is dependent on the type and degree of separation required.	For new applications, the degree of separation would have to be investigated. Foaming and scaling problems are common, requiring special measures for each application.	Field tests would be required to establish separation efficiency and potential operational problems. Energy requirements are high.
Soil washing	Soil washing	THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr90 and Cs137. Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
Solidification/stabilization	In situ auger injection	THRM/PHYS PSS-03	Accepted. In Situ Fixation Co. has dual auger equipment to inject and mix without excavation. They also have a twin, 5 ft auger system powered and moved by a standard backhoe, auger drills into soil, and a controlled nozzle system. Millgard Environmental Corp. has the MecTool system which has been approved for solidification of 80,000 cubic yards in India, and a pilot test underwater in a Canadian province.	Technology requires no scientific or technological development for this application.	Needs demonstration on a real site.

Figure 3. Thermal and physical treatment (continued).

Figure 3. Thermal and physical treatment (continued).

PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Soil washing	Soil washing THRM.PHYS - PSW-01	Demonstration, testing, and evaluation needed. Soil washing is a water based, volumetric reduction/ waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is well known and in common use in Europe. The process has been successfully demonstrated on mixed waste at the Oak Ridge National Laboratory Y-12 plant. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Technology is most effective as a waste minimization/volume reduction process. For the process to be economically feasible, the contaminated material must consist of not more than 40% passing 63 microns. The contaminated soil should contain less than 20% by volume of solid organic material. Complex waste mixtures, such as metals with organics, make washing fluid formulation difficult.	The major unit processes are: 1) a feed preparation unit, 2) an attrition scrubbing unit, 3) a size classification/desliming/thickening unit, 4) a gravity separation unit, 5) a clarification/ water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
	Vacuum vapor extraction	Vacuum vapor extraction, in situ THRM/PHYS PVV-01	Accepted. Technology has been in use for approximately 10 years. It has been proven to be very effective on volatile and semi-volatile compounds having a Henry's constant of 0.0001 or greater. It is effective in all types of soils throughout a wide range of permeabilities. It can be combined with hot air injection, steam injection, electric soil heating or air sparging to enhance the volatility of the contaminants. Also, it can be combined with groundwater extraction from the same wells. Remediation time is between six months to three years. Secondary waste streams include offgas emissions and contaminated water. Estimated costs are between 10 to 100 dollars per ton.	Special concerns in remediating radioactive waste sites are minimization of exposure to workers and potential radioactive contamination. Remote handling capabilities need to be developed.	Personnel requirements are greatest at startup and diminish with time. Once operational requirements are defined treatment can continue unsupervised with scheduled maintenance and system monitoring. Major components include extraction wells, manifold piping, vapor/liquid separator, activated carbon units or catalytic oxidizer, vacuum unit, manifold and instrumentation.
	Solidification/stabilization	Cementitious THRM.PHYS PSS-01	Demonstration, testing, and evaluation. Cementitious treatment using Portland Cement has been used extensively for treatment of LLW in the nuclear power industry. It has also been used frequently for treatment of RCRA hazardous waste where SS has been determined Best Demonstrated Available Technology (BDAT).	Additional development work is needed to develop cement formulations for mixed waste containing oil and grease, and to minimize the increase in the treated waste volume. This should be focused on known large amounts of mixed waste for which cementitious SS is judged to be a top candidate treatment method.	Cementitious system; utilize solids handling equipment such as belt conveyors, liquid solid mixers, gravimetric feed belts, and feed hoppers with vibrating bin bottoms for cement and other solid additives.
		Polymer solidification THRM.PHYS PSS-02	Demonstration, testing, and evaluation needed. In situ macroencapsulation exists for polymer encapsulation of spent ion exchange resins used in removing radionuclides from liquid streams. Dewatering of the ion exchange resins is required prior to addition of binder. Macroencapsulation takes place in the drum as fluid material fills the voids and solidifies/polymerizes. Diversified Technologies uses a vinyl ester resin in situ system (VERI), and the monolith is created by a polymerization reaction between monomer, catalyst, and promoter. Other processes use molten polyethylene which is pumped to the drum using a heated extruder. These are basically off-the shelf items.	The technology has been developed for radioactively contaminated spent ion exchange resins. If this technology was to be used on hazardous material requiring a TCLP test, further development and testing would be required to determine what types of matrices would be amenable to passing TCLP (e.g., ion exchange resins would most likely represent an adequate matrix with heavy metal dispersion throughout on an ionic level).	Due to a new EPA ruling in 40 CFR regarding treatment of hazardous debris, the use of polymer treatment (encapsulation) will provide sufficient treatment for some hazardous debris types. A trial in situ study will exist spring at ATR by macroencapsulating circuit boards.

Figure 4. Thermal and physical treatment. Nonradioactive spill areas, spill migrations, and unconfined disposal sites.

CHEMICAL AND PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
<p>Soil treatment</p> <p>Vacuum vapor extraction</p> <p>Soil washing</p>	<p>Vacuum vapor extraction - in situ THRM/PHYS PVV-01</p> <p>Soil washing THRM/PHYS PSW-01</p>	<p>Accepted</p> <p>Technology has been in use for approximately 10 years. Has been proven to be very effective on volatile and semi-volatile compounds having a Henry's constant of 0.0001 or greater. Is effective in all types of soils throughout a wide range of permeabilities. Can be combined with hot air injection, steam injection, electric soil heating, or air sparging, to enhance the volatility of the contaminants. Also can be combined with groundwater extraction from the same wells. Remediation time between 6 months to three years. Secondary waste streams include off-gas emissions and contaminated water. Estimated costs are between 10 to 100 dollars per ton.</p> <p>Accepted.</p> <p>Soil washing is a water based, volumetric reduction/ waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is widely used in Europe. Typical hazardous contaminants which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, and pesticides.</p>	<p>Technology requires no scientific or technological development.</p> <p>Technology requires no scientific or technological development for this application.</p>	<p>Personnel requirements are greatest at startup and diminish with time. Once operational requirements are defined, treatment can continue unsupervised with scheduled maintenance and system monitoring. Major components include extraction wells, manifold piping, vapor/liquid separator, activated carbon units or catalytic oxidizer, vacuum unit, manifold and instrumentation. Spent carbon units or catalytic oxidizers will require further treatment.</p> <p>Normal implementation needs. Residuals will require further treatment or disposal in a RCRA subtitle C facility.</p>
<p>Gravimetric treatment</p> <p>Thermal desorption</p> <p>Amalgamation</p>	<p>Gravity based separations</p> <p>Centrifugal separation THRM/PHYS PG-01</p> <p>Externally fired roaster THRM/PHYS TD-04</p> <p>Amalgamation THRM/PHYS PA-01</p>	<p>Demonstration, testing, and evaluation needed</p> <p>Centrifugation is an off-the-shelf technology that can be tailored to a variety of applications. It could easily be modified for use with radioactive or mixed wastes.</p> <p>Accepted.</p> <p>for non-radiologically contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9. Utilized treatment technology for Resolve Superfund Site in Massachusetts, in which PCBs were removed from soil. Laboratory scale processing of mercury and uranium contaminated soil at Oak Ridge National Laboratory.</p> <p>Demonstration, testing, and evaluation needed</p> <p>The INEL has treated mercury in a bench-scale mode to pass TCLP. A pilot scale unit will be permitted in one to two years. There are no commercial units presently available to treat large quantities of elemental mercury.</p>	<p>Plugging of a centrifugal system is a common problem that would have to be resolved for each application. Below 0.5%wt solids, separation is ineffective. Incomplete separations necessitate secondary treatments.</p> <p>Technology requires no scientific or technology development for this application.</p> <p>The pilot scale unit will require some testing since the equipment will differ slightly from the bench-scale equipment (INEL). It still needs to be determined if some DOE or comparable facility has developed this system at pilot level.</p>	<p>Depending on the separation required, field tests would be needed to determine the efficiency of the system. Secondary treatment systems would have to be designed and installed.</p> <p>Normal implementation needs. Treatment costs are low.</p> <p>The equipment for performing this amalgamation is inexpensive (paint shaker). All debris or materials should be separated away from the mercury prior to amalgamation. If not much elemental mercury is present (<1 liter) bench-scale procedures should be adequate.</p>

THERMAL AND PHYSICAL TREATMENT

Figure 4. Thermal and physical treatment (continued).

AND PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing	Soil washing THRM/PHYS PSW 01	Accepted Soil washing is a water based, volumetric reduction/waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is well known and in common use in Europe.	Technology is most effective as a waste minimization/volume reduction process. For the process to be economically feasible, the contaminated material must consist of not more than 40% passing 63 microns. The contaminated soil should contain less than 20% by volume of solid organic material. Complex waste mixtures, such as metals with organics, make washing fluid formulation difficult.	Normal implementation needs. Rinse may need to be deactivated. Neutralization of soil wash residue may require chemical neutralization prior to disposal.
Incineration	Rotary kiln incineration THRM/PHYS TI 02	Accepted Rocky Flats tested a 45 kg/h, but it was never operated on a production basis due to problems associated with the facility that housed the unit. INEL tested a rotary kiln for thousands of hours with successful results. The INEL kiln was not operated with hazardous waste because of DOE permitting problems. Oak Ridge has treated low-level radioactive liquid wastes in a rotary kiln at 270 kg/h, but has not processed solid materials due to regulatory issues associated with disposal of ash.	None	Normal implementation needs. Treatment costs are low. Regulatory issues associated with disposal of ash and solids have not been adequately resolved. Costs for nonradioactive hazardous wastes are approximately \$180.00/ton.
Thermal desorption	Indirect heated screw conveyor THRM/PHYS TD 06	Accepted Commercially available for non-radioactive treatment of volatile and semivolatile contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.
	Anaerobic thermal processor THRM/PHYS TD 07	Accepted Commercially available for non-radioactive treatment of volatile, semi-volatile and PCB contaminated soils.	None within the established envelope(s) of operation.	Design modifications for radioactive environments and maintenance reliability validation via hot testing.
Soil washing	Soil washing THRM/PHYS PSW 01	Demonstration, testing, and evaluation needed. Soil washing is a water based, volumetric reduction/waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is well known and in common use in Europe. The process has been successfully demonstrated on mixed waste at the Oak Ridge National Laboratory Y-12 plant. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Technology requires no scientific or technological development for this application.	The major unit processes are: a feed preparation unit, an attrition scrubbing unit, a size classification/desliming/thickening unit, a gravity separation unit, a clarification water treatment unit, and a dewatering unit.
Incineration	Controlled air incineration THRM/PHYS TI 01	Accepted Four DOE Facilities have used Controlled Air Incineration to process low level radioactive wastes.	No further development needed. Some adaption may be needed for large, bulky or fusible residues.	Normal implementation needs. Specific wastes must be characterized and sized.
	Rotary kiln direct THRM/PHYS TD 02	Accepted for nonradioactive contaminated hazardous waste and has been used at several EPA Superfund sites. The process is most amenable to hydrocarbon contaminated soils and sludges.	Development Test the equipment with hazardous and radioactive materials to ensure that permit requirements can be met. Feed system development for radioactive waste. Waste characterization in support of production. Secondary waste minimization. Maintenance. Scrubber technology.	Normal implementation needs. Treatment costs should be fairly low, depending on the secondary offgas cleanup systems required. Wide Beach Superfund Site costs were approximately \$185.00/ton.

Figure 4. Thermal and physical treatment (continued).

PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Water based reactive plasma THRM/PHYS PF-01	Research and development needed. This is a conceptual technology which had limited initial testing at the INEL. This technology needs further support for development. A bench scale model has been developed at the INEL.	Process development is needed to determine the process DRE and to demonstrate the process economics. This technology only needs short term development.	Implementation of the process commercially requires research and development of the bench scale and good characterization of the test data for EPA approval.
Thermal degradation	Supercritical water oxidation THRM/PHYS TO-02	Research and development needed. Bench-scale and pilot-scale tests have been performed on some hazardous wastes. The technology shows strong promise for treatment of oxidizable hazardous wastes, with demonstrated destruction efficiencies as high as 99.9999%. Can be operated in a closed process batch cycle, which could be extremely useful for treatment of radiologically contaminated wastes. Research work is currently being funded through the INEL for advancement of this technology.	Specific wastestreams must be pilot tested. Equipment corrosion problems must be solved. A better theoretical base must be established for chemical reactions in supercritical water.	High pressure system hardware required.
Thermal desorption	Externally fired roaster THRM PHYS TD 04	Accepted	Technology requires no scientific or technological development for this application	Normal implementation needs. Treatment costs low
Incineration	Liquid injection combustor THRM PHYS TI 04	Accepted Various units are commercially available. Units have been tested on hazardous materials. Units can dispose of any combustible liquid with a viscosity of less than 10,000 SSU including slurries	Technology requires no scientific or technological development for this application	Normal implementation needs
	Industrial boiler THRM PHYS TI 05	Accepted for nonradioactive wastes	Technology requires no scientific or technological development for this application	Normal implementation needs
	Rotary kiln direct THRM PHYS TD 02	Accepted The process is most amenable to hydrocarbon contaminated soils and sludges	Technology requires no scientific or technological development for this application	Normal implementation needs. Treatment costs should be fairly low, depending on the secondary offgas cleanup systems required. Wide Beach Superfund Site costs were approximately \$185.00/ton
	Water based reactive plasma THRM/PHYS PF-01	Research and development needed. This is a conceptual technology which had limited initial testing at the INEL. This technology needs further support for development. A bench scale model has been developed at the INEL.	Process development is needed to determine the process DRE and to demonstrate the process economics. This technology only needs short term development.	Implementation of the process commercially requires research and development of the bench scale and good characterization of the test data for EPA approval.
Thermal desorption	Externally fired roaster THRM PHYS TD 04	Accepted	Technology requires no scientific or technological development for this application	Normal implementation needs. Treatment costs low

Figure 4. Thermal and physical treatment (continued).

ND PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
s	Incineration	Liquid injection combustor THRM/PHYS TI-04	Accepted. Various units are commercially available. Units have been tested on hazardous materials. Units can dispose of any combustible liquid with a viscosity of less than 10,000 SSU including slurries.	Technology requires no scientific or technological development for this application	Normal implementation needs. Treatment costs low.
		Industrial boiler THRM/PHYS TI-05	Accepted. for nonradioactive wastes.	Technology requires no scientific or technological development for this application	Normal implementation needs.
		Rotary kiln - direct THRM/PHYS TD-02	Accepted. The process is most amenable to hydrocarbon contaminated soils and sludges.	Technology requires no scientific or technological development for this application	Normal implementation needs.
nent	Vacuum vapor extraction	Vacuum vapor extraction - in situ THRM/PHYS PVV-01	Accepted. Technology has been in use for approximately 10 years. Has been proven to be very effective on volatile and semi-volatile compounds having a Henry's constant of 0.0001 or greater. Is effective in all types of soils throughout a wide range of permeabilities. Can be combined with hot air injection, steam injection, electric soil heating, or air sparging, to enhance the volatility of the contaminants. Also can be combined with groundwater extraction from the same wells. Remediation time between 6 months to three years. Secondary waste streams include off-gas emissions and contaminated water. Estimated costs are between 10 to 100 dollars per ton.	Technology requires no scientific or technological development for this application	Personnel requirements are greatest at startup and diminish with time. Once operational requirements are defined, treatment can continue unsupervised with scheduled maintenance and system monitoring. Major components include extraction wells, manifold piping, vapor/liquid separator, activated carbon units or catalytic oxidizer, vacuum unit, manifold and instrumentation. Filter material from VVE will require thermal treatment.
	Thermal desorption	Externally fired roaster THRM/PHYS TD-04	Accepted. for nonradioactive contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9.	Technology requires no scientific or technological development for this application	Incineration of organic materials will be required.
	Incineration	Rotary kiln - direct THRM/PHYS TD-02	Accepted. for nonradioactive contaminated hazardous waste and has been used at several EPA Superfund sites. The process is most amenable to hydrocarbon contaminated soils and sludges.	Technology requires no scientific or technological development for this application	Normal implementation needs. Ash from incineration may have to be treated prior to disposal.
		Controlled air incineration THRM/PHYS TI-01	Accepted. Four DOE Facilities have used Controlled Air Incineration to process low level radioactive wastes.	Technology requires no scientific or technological development for this application	Normal implementation needs. Incinerator ash may require stabilization prior to disposal.
		Liquid injection combustor THRM/PHYS TI-04	Accepted. Various units are commercially available. Units have been tested on hazardous materials. Units can dispose of any combustible liquid with a viscosity of less than 10,000 SSU including slurries.	Technology requires no scientific or technological development for this application	Normal implementation needs.
	Thermal degradation	Wet air oxidation THRM/PHYS TO-01	Research and development needed. The technology is operational, but specific applications have to be researched. Methods for treating halogenated species must be devised.	Develop methods for treating halogenated materials.	High pressure system hardware required.

Figure 4. Thermal and physical treatment (continued).

AL AND PHYSICAL TREATMENT

lements	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
		Supercritical water oxidation THRM/PHYS TO-02	Research and development needed. The INEL is preparing for a series of pilot-scale tests on surrogate mixed wastes. The technology shows strong promise for treatment of oxidizable hazardous wastes, with demonstrated destruction efficiencies as high as 99.9999%. Can be operated in a closed process batch cycle. Research work is currently being funded through the INEL for advancement of this technology.	Specific wastestreams must be pilot tested. Equipment corrosion problems must be solved. A better theoretical base must be established for chemical reactions in supercritical water.	High pressure system hardware required.
	Solidification/stabilization	Cementitious THRM/PHYS PSS-01	Demonstration, testing, and evaluation needed. Cementitious treatment using Portland Cement has been used frequently for treatment of RCRA hazardous waste where S/S has been determined Best Demonstrated Available Technology (BDAT).	Additional development work is needed to develop cement formulations for mixed waste containing oil and grease, and to minimize the increase in the treated waste volume. This should be focused on known large amounts of mixed waste for which cementitious S/S is judged to be a top candidate treatment method.	Cementitious systems utilize solids handling equipment such as belt conveyors, liquid/solid mixers, gravimetric feed belts, and feed hoppers with vibrating bin-bottoms for cement and other solid additives.

THERMAL AND PHYSICAL T

Figure 5. Thermal and physical treatments. Radioactive spill areas, spill migrations and unconfined disposal sites.

AND PHYSICAL TREATMENT

ts	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing	Soil washing	THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr ⁹⁰ and Cs ¹³⁷ . Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, and from clay soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
Thermal desorption	Thermal desorption	Rotary kiln indirect THRM/PHYS TD 03	Accepted for nonradioactive contaminated hazardous waste and has been used at several EPA Superfund sites. The process is most amenable to hydrocarbon contaminated soils and sludges.	Development. Test the equipment with hazardous and radioactive materials to ensure that permit requirements can be met. Feed system development for radioactive waste. Secondary waste minimization. Maintenance. Scrubber technology.	Normal. Implementation needs. Treatment costs should be fairly low, depending on the secondary offgas cleanup systems required. Wide Beach Superfund Site costs were approximately \$185.00 ton.
Amalgamation	Amalgamation	THRM/PHYS PA 01	Demonstration, testing, and evaluation needed. The INEL has treated mercury in a bench scale mode to pass TCLP. A pilot scale unit will be permitted in one to two years. There are no commercial units presently available to treat large quantities of elemental mercury.	The pilot scale unit will require some testing since the equipment will differ slightly from the bench scale equipment (INEL). It still needs to be determined if some DOE or comparable facility has developed this system at pilot level.	The equipment for performing this amalgamation is inexpensive (pneumatic shakers). All debris or materials should be separated away from the mercury prior to amalgamation. If not much elemental mercury is present (< 1 liter), bench scale procedures should be adequate.
Blasting method	CO ₂ blasting	THRM/PHYS PB 01	Accepted. Technology has been in development over the last ten years and has been bench scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose surface contamination and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 g/sq. ft. Basically a line of sight cleaning method, limited effect around corners, or in deep channels. No secondary wastes are generated.	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also, the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000 and operating costs are estimated to range from \$15/hr. for industrial cleaning applications to \$300/hr. for radioactive contamination removal. Equipment requirements include a pelletizer to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. An air enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.
	Sand blasting	THRM/PHYS PB 03	Accepted. A long standing, successful and well understood technology. Generates secondary waste stream.	Technology has no science or technology needs for this application.	Normal. Implementation needs. Secondary waste stream from blasting may require further treatment prior to disposal.
	Water crystalline blasting	THRM/PHYS PB 02	Accepted. Technology has been in development for several years and has been shown to be very effective at removing both loose and fixed contamination.	Technology has no science or technology needs for this application.	A high efficiency blast nozzle is necessary to transfer energy from blast air to ice particles.

Figure 5. Thermal and physical treatment (continued).

AL AND PHYSICAL TREATMENT

THERMAL AND PHYSICAL T

Figure 5. Thermal and physical treatment (continued).

ND PHYSICAL TREATMENT

Figure 5. Thermal and physical treatment (continued).

L AND PHYSICAL TREATMENT

ments	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
al treatment	Blasting method	CO ₂ blasting THRM/PHYS PB-01	Accepted. Technology has been in development over the last ten years and has been bench-scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose, surface contamination, and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 lbs./hr. Basically, a line of sight cleaning method, limited effect around corners, or in deep channels. No secondary wastes are generated. Not effective on concrete	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also, the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000, and operating costs are estimated to range from \$15/hr., for industrial cleaning applications, to \$300/hr., for radioactive contamination removal. Equipment requirements include a pelletizer, to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. Also, an enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.
		Sand blasting THRM/PHYS PB-03	Accepted. A long standing, successful, and well understood technology. Generates secondary waste stream	Technology has no science or technology needs for this application.	Normal implementation needs. Secondary waste stream from blasting may require further treatment prior to disposal
		Water crystal (ice) blasting THRM/PHYS PB-02	Accepted. Technology has been in development for several years and has been shown to be very effective at removing both loose and fixed contamination.	Technology has no science or technology needs for this application.	A high efficiency blast nozzle is necessary to transfer energy from blast air to ice particles.
	Soil washing	Soil washing THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr ⁹⁰ and Cs ¹³⁷ . Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, and from clay soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
treatment	Blasting method	CO ₂ blasting THRM/PHYS PB-01	Accepted. Technology has been in development over the last ten years and has been bench-scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose, surface contamination, and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 lbs./hr. Basically, a line of sight cleaning method, limited effect around corners, or in deep channels. No secondary wastes are generated.	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000, and operating costs are estimated to range from \$15/hr., for industrial cleaning applications, to \$300/hr., for radioactive contamination removal. Equipment requirements include a pelletizer, to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. Also, an enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.

THERMAL AND PHYSICAL

Figure 5. Thermal and physical treatment (continued).

ID PHYSICAL TREATMENT

THERMAL AND PHYSIC

Figure 5. Thermal and physical treatment (continued).

Figure 5. Thermal and physical treatment (continued).

D PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
nt	Blasting method	CO ₂ blasting THRM/PHYS PB-01	Accepted. Technology has been in development over the last ten years and has been bench-scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose, surface contamination, and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 lbs./hr. Basically, a line of sight cleaning method. Limited effect around corners, or in deep channels. No secondary wastes are generated.	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also, the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000, and operating costs are estimated to range from \$15/hr. for industrial cleaning applications, to \$300/hr. for radioactive contamination removal. Equipment requirements include a pelletizer, to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. Also, an enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.
		Sand blasting THRM/PHYS PB-03	Accepted. A long standing, successful, and well understood technology. Generates secondary waste stream.	Technology has no science or technology needs for this application.	Normal implementation needs. Secondary waste stream from blasting may require further treatment prior to disposal.
		Water crystal (ice) blasting THRM/PHYS PB-02	Accepted. Technology has been in development for several years and has been shown to be very effective at removing both loose and fixed contamination.	Technology has no science or technology needs for this application.	A high efficiency blast nozzle is necessary to transfer energy from blast air to ice particles.
	Soil washing	Soil washing THRM/PHYS PSW-01	Research and development needed for soils at INEL containing Sr ⁹⁰ and Cs ¹³⁷ . Soil washing is a water based, volumetric reduction/waste minimization process, whereby radiological contaminants are extracted and concentrated into a small residual portion of the original volume. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Perform soil washing studies for removing Radiological Contaminants. Basic R & D into INEL soil science, and from clay soil binding characteristics.	The major unit processes are: 1) a feed preparation unit where feedstock is tumbled and washed with high pressure water sprays in a rotating trommel screen; 2) an attrition scrubbing unit to remove surficial contaminants from individual sand grains; 3) a size classification/desliming/thickening unit to remove clays which are a primary host to the contaminants; 4) a gravity separation unit to remove solid organic materials or to separate high specific gravity contaminants which exist as discrete particles; 5) a clarification/water treatment unit to remove contaminants from the wash water for reuse; and 6) a dewatering unit to prepare the contaminant laden fines for the appropriate ultimate destruction or immobilization process.
ant	Blasting method	CO ₂ blasting THRM/PHYS PB-01	Accepted. Technology has been in development over the last ten years and has been bench-scale tested at the Rocky Flats Plant on contaminated materials. Very effective in removing both loose, surface contamination, and fixed contamination from metal surfaces. During Rocky Flats tests, cleaning rates ranged from approximately 50 to 90 lbs./hr. Basically, a line of sight cleaning method. Limited effect around corners, or in deep channels. No secondary wastes are generated. Not effective on concrete.	Of the two systems tested at Rocky Flats, neither was totally efficient in the use of CO ₂ pellets. One of the systems caused a buildup of ice on the object being cleaned and also in the room, causing the air filters to become clogged. Also, the decontamination room developed a buildup of CO ₂ gas above OSHA allowable limits.	Capital costs are in the order of \$300,000, and operating costs are estimated to range from \$15/hr. for industrial cleaning applications, to \$300/hr. for radioactive contamination removal. Equipment requirements include a pelletizer, to manufacture CO ₂ pellets, an air compressor, an air dryer, and a liquid carbon dioxide storage tank. Also, an enclosure to contain the airborne contaminants and a HEPA filtration system to filter the exhaust air would be needed.

Figure 5. Thermal and physical treatment (continued).

AL AND PHYSICAL TREATMENT

THERMAL AND PHYSICAL T AND PHYSICAL TREATMENT

Figure 5. Thermal and physical treatment (continued).

Figure 6. Thermal and physical treatment. Injection wells, groundwater, and associated plumes.

AND PHYSICAL TREATMENT

ents	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
------	--------------	--------------	--------	------------------------------	----------------------

treatment → Not enough information to discuss
technology for this site.

THERMAL AND PHYSICAL T

Figure 7. Thermal and physical treatment. Unexploded naval ordnance.

ND PHYSICAL TREATMENT

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Soil washing	Soil washing THRM/PHYS PSW-01	Research and development needed. Soil washing is a water based, volumetric reduction/ waste minimization process, whereby hazardous contaminants are extracted and concentrated into a small residual portion of the original volume. The technology is well known and in common use in Europe. The process has been successfully demonstrated on mixed waste at the Oak Ridge National Laboratory Y-12 plant. Typical hazardous contaminant groups which can be effectively removed include petroleum and fuel residues, radionuclides, heavy metals, PCB, PCP, and pesticides.	Technology is most effective as a waste minimization/volume reduction process. For the process to be economically feasible, the contaminated material must consist of not more than 40% passing 63 microns. The contaminated soil should contain less than 20% by volume of solid organic material. Complex waste mixtures, such as metals with organics, make washing fluid formulation difficult.	The major unit processes are: 1) a feed preparation unit, 2) an attrition scrubbing unit, 3) a size classification/ desliming/thickening unit, 4) a gravity separation unit, 5) a clarification/ water treatment unit and a dewatering unit
Thermal desorption	Rotary kiln - indirect THRM/PHYS TD-03	Accepted. for nonradioactive contaminated hazardous waste, and has been used at several EPA Superfund sites. The process is most amenable to hydrocarbon contaminated soils and sludges.	No scientific or technological development required for this application	Normal implementation needs. Treatment costs are low
Incineration	Controlled air incineration THRM/PHYS TI-01	Accepted. Four DOE Facilities have used Controlled Air Incineration to process low level radioactive wastes.	No further development needed. Some adaption may be needed for large, bulky or fusible residues.	Normal implementation needs. Specific wastes must be characterized and sized
	Liquid injection combustor THRM/PHYS TI-04	Accepted. Various units are commercially available. Units have been tested on hazardous materials. Units can dispose of any combustible liquid with a viscosity of less than 10,000 SSU including slurries.	Liquid injection combustors must still be qualified for use with radioactive materials.	Normal implementation needs
Thermal degradation	Supercritical water oxidation THRM/PHYS TO-02	Research and development needed. Bench-scale and pilot-scale tests have been performed on some hazardous wastes. The INEL is preparing for a series of pilot-scale tests on surrogate radioactive wastes. The technology shows strong promise for treatment of oxidizable hazardous wastes, with demonstrated destruction efficiencies as high as 99.999%. Can be operated in a closed process batch cycle. Research work is currently being funded through the INEL for advancement of this technology.	Technology would need to be demonstrated on this waste stream.	High pressure system hardware required.

Figure 8. Thermal and physical treatment. Landfills.

Figure 8. Thermal and physical treatment (continued).

ND PHYSICAL TREATMENT

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
ent	Thermal desorption	Externally fired roaster THRM/PHYS TD-04	Accepted. Demonstrated for nonradioactive contaminated hazardous wastes. Process is under serious consideration for utilization in site remediation activities at INEL Pit 9.	No scientific or technological development is required for this application.	Normal implementation needs. Treatment costs should be fairly low, but will be strongly dependent on secondary treatment options, which are waste specific. Organic substance must be separated from mercury to facilitate further treatment. Mercury will require amalgamation prior to disposal.
	Incineration	Liquid injection combustor THRM/PHYS TI-04	Accepted. Various units are commercially available. Units have been tested on hazardous materials. Units can dispose of any combustible liquid with a viscosity of less than 10,000 SSU including slurries.	No scientific or technological development is required for this application.	Normal implementation needs. Mercury will require amalgamation.
	Solidification/stabilization	Cementitious THRM/PHYS PSS-01	Demonstration, testing, and evaluation needed. Cementitious treatment using Portland Cement has been used extensively for treatment of LLW in the nuclear power industry. It has also been used frequently for treatment of RCRA hazardous waste where S-S has been determined Best Demonstrated Available Technology (BDAT).	Additional development work is needed to develop cement formulations for waste containing oil and grease, and to minimize the increase in the treated waste volume. This should be focused on known large amounts of mixed waste for which cementitious S-S is judged to be a top candidate treatment method.	Cementitious. A closed systems utilize solids handling equipment such as belt conveyors, liquid/solid mixers, gravimetric feed belts, and feed hoppers with vibrating bin-bottoms for cement and other solid additives.
	Amalgamation	Amalgamation THRM/PHYS PA-01	Demonstration, testing, and evaluation needed. The INEL has treated mercury in a bench-scale mode to pass TCLP. A pilot scale unit will be permitted in one to two years. There are no commercial units presently available to treat large quantities of elemental mercury.	The pilot-scale unit will require some testing since the equipment will differ slightly from the bench-scale equipment (INEL). It still needs to be determined if some DOE or comparable facility has developed this system at pilot level.	The equipment for performing this amalgamation is inexpensive (paint shaker). All debris or materials should be separated away from the mercury prior to amalgamation. If not much elemental mercury is present (< 1 liter), bench-scale procedures should be adequate.
	Thermal degradation	Supercritical water oxidation THRM/PHYS TO-02	Research and development needed. No testing has been done on radioactive wastes. Bench-scale and pilot-scale tests have been performed on some hazardous wastes. The INEL is preparing for a series of pilot-scale tests on surrogate radioactive wastes. The technology shows strong promise for treatment of oxidizable hazardous wastes, with demonstrated destruction efficiencies as high as 99.9999%. Can be operated in a closed process batch cycle, which could be extremely useful for treatment of radiologically contaminated wastes. Research work is currently being funded through the INEL for advancement of this technology.	Equipment corrosion problems must be solved. A better theoretical base must be established for chemical reactions in supercritical water. A closed system which utilizes solids handling equipment must be developed.	High pressure system hardware required. A closed systems utilize solids handling equipment such as belt conveyors, liquid/solid mixers, gravimetric feed belts, and feed hoppers with vibrating bin-bottoms for cement and other solid additives.

Caps and Ba

The Caps and Barriers section of this TLD addresses technologies that contain and is

1. Caps
2. Water balance caps

and Barriers

s that contain and isolate wastes in place. Options for Caps and Barriers are as follows:

CAPS AND BARRIER

Figure 1. Caps and barriers. Radioactive underground storage tanks, aboveground storage tanks, and associated soils.

AND BARRIERS

Figure 1. Caps and barriers (continued).

RECAPS AND BARRIERS

CAPS AND BARRIER

Figure 1. Caps and barriers (continued).

AND BARRIERS

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
<div>Caps CB-01</div>	<div>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi-layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</div>	<div>Accepted. Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages. The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</div>	<div>For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</div>	<div>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation. Due to potential difficulties with close proximity to other buildings, capping may not be a feasible option.</div>
<div>Water balance caps CB-02</div>	<div>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse-grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse grained soil. If the fine-grained soil layer is eventually the water will be evaporated from the fine grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.</div>	<div>Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.</div>	<div>None identified</div>	<div>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation. Due to potential difficulties with close proximity to other buildings, capping may not be a feasible option.</div>
<div>Caps CB-01</div>	<div>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi-layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</div>	<div>Accepted. Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages. The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</div>	<div>For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</div>	<div>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</div>

Figure 1. Caps and barriers (continued).

S AND BARRIERS

Concepts	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
----------	--------------	--------------	--------	------------------------------	----------------------

CAPS AND BARRIERS

Figure 2. Caps and barriers. Nonradioactive sumps, ponds, pits, trenches, rubble piles, etc.

AND BARRIERS

	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
1	<p>Caps</p> <p>CB-01</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi-layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</p>	<p>Accepted.</p> <p>Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages.</p> <p>The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</p>	<p>For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p> <p>Capping is an alternative if the mercury levels in the soil are low enough to allow minimum capping technologies to be applied.</p>
S 2	<p>Water balance caps</p> <p>CB-02</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for and sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse-grained soil. If the fine grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.</p>	<p>Demonstration, testing, and evaluation needed.</p> <p>Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.</p>	<p>None identified</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p>
01	<p>Caps</p> <p>CB-01</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi-layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</p>	<p>Accepted</p> <p>Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages.</p> <p>The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</p>	<p>For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p> <p>Capping is an alternative if the mercury levels in the soil are low enough to allow minimum capping technologies to be applied.</p>

Figure 2. Caps and barriers (continued).

RISKS AND BARRIERS

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a course-grained soil layer will hold water in capillary voids until saturated before the water will drain into the course-grained soil. If the fine-grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.
Caps CB-01	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.	Accepted. Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or pre-demonstration stages. The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.	For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation. Capping is an alternative if the mercury levels in the soil are low enough to allow minimum capping technologies to be applied.
Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a course-grained soil layer will hold water in capillary voids until saturated before the water will drain into the course-grained soil. If the fine-grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

CAPS AND BARRIERS

Figure 3. Caps and barriers. Radioactive sumps, ponds, pits, trenches, rubble piles, etc.

BARRIERS

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
<p>Caps CB 01</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sand bags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</p>	<p>Accepted</p> <p>Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages.</p> <p>The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</p>	<p>For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p> <p>In situ Stabilization followed by capping</p>
<p>Water balance caps CB 02</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse-grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse-grained soil. If the fine-grained soil layer. Eventually the water will be evaporated from the fine grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.</p>	<p>Demonstration, testing, and evaluation needed</p> <p>Demonstrations of this technology are underway at Hanford. There are full scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.</p>	<p>None identified.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p>
<p>Caps CB 01</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sand bags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</p>	<p>Accepted</p> <p>Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed many aspects of the technology are still in demonstration or predemonstration stages.</p> <p>The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</p>	<p>For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p> <p>Capping is only feasible if the building over the site is removed.</p> <p>Stabilize drain at top</p>

Figure 3. Caps and barriers (continued).

RIPS AND BARRIERS

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse-grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse-grained soil. If the fine grained soil layer Eventually the water will be evaporated from the fine grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.
Caps CB-01	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sand bags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.	Accepted. Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages. The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.	For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation. Capping technologies may be used if adequate clearance can be made between structures.
Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse-grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse-grained soil. If the fine grained soil layer Eventually the water will be evaporated from the fine grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

Figure 3. Caps and barriers (continued).

ROAD AND BARRIERS

na	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
----	--------------	--------------	--------	------------------------------	----------------------

Figure 4. Caps and barriers. Nonradioactive spill areas, spill migrations, and unconfined disposal sites.

CAPS AND BARRIERS

Figure 4. Caps and barriers (continued).

AND BARRIERS

s	Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
	Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a course-grained soil layer will hold water in capillary voids until saturated before the water will drain into the course-grained soil. If the fine-grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.
	Caps CB-01	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.	Accepted. Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or pre-demonstration stages. The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.	For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.
	Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a course-grained soil layer will hold water in capillary voids until saturated before the water will drain into the course-grained soil. If the fine-grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

Figure 5. Caps and barriers. Radioactive spill areas, spill migrations, and unconfined disposal sites.

Caps

CB-01

Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.

Accepted.
Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or pre-demonstration stages.

The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.

For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.

The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

Further study of the location may be required.

Water balance caps CB-02

Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse-grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse-grained soil. If the fine grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.

Demonstration, testing, and evaluation needed.
Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.

None identified

The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

Caps

CB-01

Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.

Accepted.
Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or pre-demonstration stages.

The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross-sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.

For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.

The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

Figure 5. Caps and barriers (continued).

RS AND BARRIERS

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a course-grained soil layer will hold water in capillary voids until saturated before the water will drain into the course-grained soil. If the fine-grained soil layer Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapo-transpiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.
Caps CB-01	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.	Accepted. Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages. The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.	For caps with soil layers additional work needs to perform in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.
Water balance caps CB-02	Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a course-grained soil layer will hold water in capillary voids until saturated before the water will drain into the course-grained soil. If the fine-grained soil layer Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapo-transpiration of water.	Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.	None identified.	The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.

Figure 6. Caps and barriers. Landfills.

CAPS AND BARRIERS

Alternatives	Technologies	Status	Science and Technology Needs	Implementation Needs
<p>Caps CB-01</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</p>	<p>Accepted</p> <p>Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages.</p> <p>The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</p>	<p>For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p>
<p>Water balance caps CB-02</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse grained soil. If the fine grained soil layer eventually the water will be evaporated from the fine grained layer. Native plants assist the upper soil layer in drying by the evapotranspiration of water.</p>	<p>Demonstration, testing, and evaluation needed.</p> <p>Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.</p>	<p>None identified</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p>
<p>Caps CB-01</p>	<p>Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. Many different barrier systems fall under the broad heading of caps. Caps may be as simple as a sheet of plastic held down by sandbags or as complex as multi layer systems which include low permeability layers, drainage layers, vegetative layers, intruder protection layers etc.</p>	<p>Accepted</p> <p>Some capping systems have become fairly common, with numerous installations nationwide. Other systems are only in the development stages. Though caps are being designed and constructed, many aspects of the technology are still in demonstration or predemonstration stages.</p> <p>The EPA published "Minimum Technology Guidance" documents for caps which outline performance standards and give recommended cross sections of caps for hazardous waste closures. Many sites have been capped in accordance with EPA guidance. Some of these caps have failed, and the EPA and the technical community is currently rethinking the technology in an effort to produce more dependable caps.</p>	<p>For caps with soil layers additional work needs to be performed in the area of desiccation of clays and the effect of desiccation on cap permeability. For geomembrane caps extensive materials testing and longevity testing is needed.</p>	<p>The use of a Technological concept should be based in part, on the determination that the concept provides the necessary degree of waste isolation.</p>

A

A

R AND BARRIERS

Alternatives

Technologies

Status

Science and Technology Needs

Implementation Needs

Water balance caps
CB-02

Capping of waste areas consists of placing a barrier over a site to prevent the infiltration of water into the waste from above. The water balanced cap is a technology developed at Hanford for arid sites. The technology is based on the principle that a fine grained soil layer overlaying a coarse-grained soil layer will hold water in capillary voids until saturated before the water will drain into the coarse grained soil. If the fine-grained soil layer. Eventually the water will be evaporated from the fine-grained layer. Native plants assist the upper soil layer in drying by the evapo-transpiration of water.

Demonstration, testing, and evaluation needed. Demonstrations of this technology are underway at Hanford. There are full-scale test plots under construction and evaluation. Numerous studies of various aspects of barrier development in arid climates have been performed at Hanford.

None identified

The use of a Technological concept should be based in part on the determination that the concept provides the necessary degree of waste isolation.

This index includes references to contaminant names, operable unit numbers, COCA site numbers, waste forms, and technology names. The index covers the text of all three volumes. Bold characters followed by a colon indicate the volume to which the following page numbers refer:

I Volume I

IA Volume I, Appendix A

IB Volume I, Appendix B

II Volume II

III Volume III.

A

Acetone, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Aluminum nitrate, **IB**:17, 19; **II**:56, 118, 185, 243, 272; **III**:33, 67, 220, 251, 294, 296

Amalgam electrowinning (BICH-017), **IA**:6, 11; **II**:136, 140, 142-146, 148, 150-151, 154-155, 157, 162-163, 165, 169, 171-172, 174, 176, 178, 180-181, 183, 186, 191, 194, 197-198, 201, 203, 205, 207, 209, 211; **III**:167-169, 175-178, 180-181, 188, 190-193, 197-198, 200-201, 204-206, 208-211

Amalgamation (THRM/PHYS PA-01), **I**:11; **IA**:6, 13; **II**:15, 37, 96, 110, 140, 164, 220-225, 230, 233, 242, 247, 258-259, 269; **III**:267-268

Americium (Am-134), **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220; **III**:251

Ametol, **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 296, 308, 311-312

Anaerobic thermal processor (ATP) (THRM/PHYS TD-07), **IA**:6, 13; **II**:228-229, 235, 240, 243; **III**:302

Annular denuder technology (CHAR 64A-IN), **IA**:3, 9; **II**:4; **III**:45

Artificial intelligence/neural network (CHAR 22-IN), **IA**:3, 9; **II**:3, 5; **III**:13

Asbestos, **IB**:8, 21; **II**:9-10, 12, 14-15, 18, 20, 22-23, 25, 38, 41, 51, 54, 65; **III**:28

Asphalt (waste form), **I**:14; **IB**:15; **II**:69, 119, 125, 199, 233, 249; **III**:3, 5, 11, 25, 27, 35, 41, 50, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 127, 177, 216, 220, 232, 247, 264, 282, 284, 286, 290

Atomic spectroscopy (AA, AE) (CHAR 76-IN), **IA**:3, 9; **II**:17, 30-31, 41, 57, 66, 83-86, 88; **III**:60-61, 103

Auger electron spectroscopy (AES) (CHAR 2-IN), **IA**:3, 9; **II**:8, 10, 12, 14, 18, 20-21, 23, 25, 38, 41, 51, 54, 65; **III**:5, 63, 66

Autocorrelation and optimized multivariant analysis (CHAR 29-IN), **IA**:3, 9; **II**:17; **III**:23

B

Beryllium, **II**:85-86, 88, 132, 214-215, 258-259, 276; **III**:7, 9, 11, 15, 31, 52, 60, 63, 65, 67, 73, 75, 79, 94, 119, 122, 135, 139, 145, 182, 184, 284, 298, 308, 312

Bioaccumulation (BICH-IL-BA, -BA2), **IA**:5, 11; **II**:135-136, 138-150, 153-162, 164, 166-183, 185-186, 190-210; **III**:217, 219, 221, 224, 227, 230, 233, 236-237, 239

Bioprecipitation (BICH-IL-BP, -BP2), **IA**:11; **II**:135-136, 138-150, 153-162, 164, 166-183, 185-186, 190-210; **III**:217, 219, 221, 224, 227, 230, 233, 236, 241, 243

Black powder, **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 259, 296, 304, 308, 311-312

Bromides, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219

C

Caps (CAPS CB-01), **I**:3, 5, 14; **IA**:7, 13; **II**:263-277; **III**:315, 317, 319

Carbon dioxide blasting (THRM/PHYS PB-01), **IA**:6, 13; **II**:219, 221, 234-235, 237, 247-248, 250-254; **III**:269

Carbon tetrachloride, **IB**:5, 24, 27; **II**:7, 9, 11, 53, 59, 94-95, 117, 119, 137, 182, 189, 240, 245, 271; **III**:3, 5, 7, 11, 25, 27, 29, 35, 41, 50, 67, 69, 73, 75, 85, 87, 91, 97, 102, 104, 119, 136, 140, 146, 204, 216, 223, 232, 255, 257, 259, 282, 284, 286, 292, 294, 296, 300, 302, 306, 308, 311-312

Carbon, 220

Cementite, **II**:22, 258-259

Centrifuge, 13; **I**

Cerium, 3

Cesium, 165, 194, 226;

Cesium-137, 42, 4, 101, 150, 202, 247-248, 9, 11, 50, 5, 87, 9, 146, 218, 243, 286,

Cesium-134, 12, 1, 45, 4, 73, 7, 130, 148, 176, 202, 247-248,

9, 11, 41, 4, 79, 8, 122, 162, 197, 229, 263, 290,

Cesium-137, 265; 37, 4, 97, 1, 153, 237,

INDEX

Carbon, organic, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Cementitious (THRM/PHYS PSS-01), **IA**:6, 13; **II**:220-222, 224, 226, 228-230, 232, 241, 246, 258-259; **III**:284-285

Centrifugal separation (THRM/PHYS PG-01), **IA**:6, 13; **II**:242; **III**:281

Cerium, **IB**:17

Cesium, **IB**:17; **II**:136, 142, 144, 148, 151, 163, 165, 169, 171-172, 174, 176, 178, 180-181, 194, 197-198, 201, 203, 205, 207, 209, 211, 226; **III**:167, 169, 175, 177, 180, 197, 200, 212

Cesium-134, **IB**:5, 7, 12-18; **II**:7, 9, 11-12, 15, 26, 42, 44, 48, 50, 64, 68-70, 72-73, 75, 78, 94-96, 101, 112-113, 115, 123-129, 137-138, 140, 150, 168-169, 174, 176, 194, 197, 199-200, 202, 204-205, 208, 219-222, 226, 236-238, 247-253, 264-265, 269-270, 274-275; **III**:3, 5, 9, 11, 15, 17, 23, 25, 27, 31, 35, 37, 41, 43, 50, 52, 58, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 101-102, 104, 110, 119, 122, 129, 146, 150, 153, 159, 162, 177, 188, 190, 216, 218, 220, 223, 226, 229, 232, 235, 237, 241, 243, 245, 247, 249, 271, 274, 279, 282, 284, 286, 288, 290, 296, 298, 304, 308

Cesium-137, **I**:3; **IB**:4-7, 9-18, 22; **II**:6-7, 9, 11-12, 14-15, 17, 19, 21-22, 24, 26, 36-37, 42, 44-45, 47-48, 50, 52, 60-61, 63-64, 66, 68-70, 72-73, 75, 78, 80, 93-101, 109-110, 112-117, 121-130, 135, 137-138, 140-141, 143, 145, 147-148, 150, 163-164, 168-169, 171, 173-174, 176, 179-180, 190-191, 193-195, 197, 199-200, 202, 204-205, 208-209, 219-226, 233, 236-239, 247-254, 263-266, 269-270, 274-275; **III**:3, 5, 9, 11, 15, 17, 23, 25, 27, 29, 31, 33, 35, 37, 41, 43, 50, 52, 58, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 95, 97, 101-102, 104, 110, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 162, 167, 169, 175, 177, 180, 188, 190, 192, 197, 200, 206, 214, 216, 218, 220, 223, 226, 229, 232, 235, 237, 241, 243, 245, 247, 249, 263, 269, 271, 273-274, 282, 284, 286, 288, 290, 294, 296, 298, 304, 306, 308

Cesium-144, **IB**:7; **II**:15, 96, 138, 140, 221-222, 265; **III**:3, 5, 9, 11, 15, 17, 23, 25, 27, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 77, 79, 87, 91, 97, 101-102, 104, 110, 119, 122, 146, 150, 153, 159, 162, 188, 190, 212, 216, 223, 232, 237, 243, 247, 279, 284, 286

CFA-02, **IB**:21; **II**:85, 132, 214, 258, 276; **III**:7, 9, 11, 15, 31, 52, 60, 63, 65, 67, 73, 75, 79, 95, 122, 129, 136, 140, 182, 184, 255, 257, 267, 284, 298, 308, 312

CFA-03, **IB**:21; **II**:87, 132, 215, 259, 276; **III**:7, 9, 11, 15, 52, 60, 63, 67, 73, 75, 79, 95, 102, 104, 106, 108, 110, 122, 129, 136, 140, 182, 255, 267, 284, 298, 308, 312

CFA-04, **IB**:20; **II**:33, 107, 160, 230, 268; **III**:11, 31, 52, 67, 119, 122, 129, 140, 173, 267, 298

CFA-06, **IB**:20; **II**:34, 107, 161, 232; **III**:11, 31, 67, 122, 129, 210, 212, 216, 223, 232, 284, 286

CFA-10, **IB**:20; **II**:57, 118, 186, 243; **III**:67, 83, 119, 122, 129, 202, 255, 259, 276, 294, 304, 312

CFA-17, **IB**:20; **II**:34, 107, 160, 230; **III**:11, 31, 52, 67, 122, 129, 162, 253, 255, 276, 292, 294, 296, 304, 306, 312

CFA-26, **IB**:21; **II**:58, 119, 187, 244, 273; **III**:52, 67, 73, 99, 122, 129, 186, 253, 255, 259, 276, 294, 298, 308, 310

CFA-42, **IB**:21; **II**:58, 119, 188, 244; **III**:52, 67, 73, 99, 122, 129, 195, 253, 255, 259, 294, 298, 308, 310

CFA-43, **IB**:20; **II**:34, 108, 162, 232; **III**:11, 31, 52, 67, 122, 129, 282, 284, 286

CFA-44, **IB**:20; **II**:57, 118, 185, 243; **III**:7, 11, 31, 52, 60, 63, 67, 73, 122, 129, 208, 214, 220, 229, 257, 290, 300, 302, 306

Chemical precipitation (BICH-I-CP), **IA**:5, 11; **II**:135-149, 153-162, 164, 166-183, 185-186, 190-210; **III**:212, 217, 219, 221, 224, 227, 230, 233, 236

Chemical washing (BICH-I-CW, -CW2, -CW2B), **I**:10; **IA**:5, 11; **II**:135-136, 138, 141-148, 150-151, 153-155, 157-166, 168-182, 184-188, 190, 192-194, 196-211, 214-215; **III**:167-171, 173-178, 180-184, 186, 192, 195, 197-198, 200-202, 208-211, 214, 216, 218

Chemical washing (cesium and strontium) (BICH-012), **IA**:5, 11; **II**:144, 148, 172, 174, 194, 197, 211; **III**:180

Chemical washing (cesium) (BICH-011), **IA**:5, 11; **II**:142, 144, 148, 151, 169, 171-172, 174, 176,

- 178, 194, 197-198, 201, 203, 205, 207, 209, 211; **III**:169, 177, 180
- Chemical washing (cesium, strontium, and plutonium) (BICH-004), **IA**:5, 11; **II**:142; **III**:169
- Chemical washing (chromium, mercury, and beryllium) (BICH-013, -014), **IA**:5, 11; **II**:214-215; **III**:182, 184
- Chemical washing (cobalt & cesium) (BICH-009), **IA**:6, 11; **II**:180; **III**:175
- Chemical washing (cobalt, cesium, and mercury) (BICH-025, -026), **IA**:6, 11; **II**:165, 181; **III**:197
- Chemical washing (cobalt, cesium, and strontium) (BICH-001), **IA**:6, 11; **II**:136, 163; **III**:167
- Chemical washing (mercury) (BICH-007), **IA**:6, 11; **II**:160, 184; **III**:173
- Chemical washing - organics (BICH-016), **IA**:5, 11; **II**:184, 188; **III**:186
- Chemical washing - PCBs (BICH-030), **IA**:6, 11; **II**:187; **III**:202
- Chloroform, **IB**:24, 27; **II**:59, 119, 189, 245; **III**:7, 73, 75, 255, 259, 292, 294, 308, 311-312
- Chromium, **I**:8; **IB**:4-5, 7-8, 21-22; **II**:7, 9, 11, 33, 52, 85-86, 88, 94-95, 105-106, 117, 132, 137, 157-160, 180-181, 214-215, 219-220, 239, 258-259, 276; **III**:3-7, 9-13, 15, 18-19, 21, 24-28, 30-32, 34, 38-39, 41-43, 48, 50-54, 56, 58, 60-61, 63-68, 70, 73, 75, 79-80, 91, 95-96, 102, 104, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 171, 182, 184, 200, 212, 214, 216, 220, 223, 229, 232, 245, 284, 286, 288, 290, 298, 306, 312
- Chromium, hexavalent (Cr VI), **II**:11, 94-95, 137, 219-220
- Chromium, trivalent (Cr III), **II**:33, 94-95, 106, 137, 159, 219-220; **III**:9, 11, 52, 60, 63, 65, 67, 79, 95, 129, 136, 140, 150, 157, 159, 171, 212, 216, 223, 232, 284, 286
- Cobalt, **I**:5-7, 17-18; **IB**:3-4, 6-8, 10, 12, 17-22, 29; **II**:135-136, 138, 141, 143, 145, 147, 149, 153-154, 156-157, 159, 161, 163-165, 167-170, 172-173, 175, 177, 179-182, 185, 190, 192-194, 196, 198-199, 201, 203-204, 206, 208, 210, 233, 239; **III**:125-128, 133-134, 138-139, 142-143, 148, 155-156, 161, 167, 175, 197, 200, 220, 223, 226, 288-289
- Cobalt-57, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220
- Cobalt-60, **I**:3; **IB**:4-7, 22, 27; **II**:6-7, 9, 11-12, 14-15, 37, 52-53, 93-96, 109-110, 116-117, 135, 137-138, 140, 163-164, 179-180, 182, 219-222, 233, 239-240, 263-265, 269, 271; **III**:3, 5, 7, 9, 11, 15, 17, 23, 25, 27, 29, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 69, 71, 73, 75, 77, 79, 85, 87, 91, 95, 97, 101-102, 104, 110, 119, 122, 129, 136, 140, 146, 150, 153, 159, 162, 167, 175, 188, 190, 200, 204, 212, 214, 216, 218, 220, 223, 226, 229, 232, 235, 237, 243, 245, 247, 249, 257, 263, 269, 271, 273-274, 279, 282, 284, 286, 288, 290, 294, 296, 298, 300, 302, 304, 306, 308, 312
- Cold dilute potassium hydroxide washing (BICH-032), **IA**:6, 11; **II**:191; **III**:206
- Cold vapor (mercury) (CHAR 24-IN), **IA**:3, 9; **II**:17, 30-31, 41, 56, 66, 85-86, 88; **III**:15
- Composition B, **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 259, 296, 304, 308, 311-312
- Concrete (waste form), **I**:3, 9, 14; **IB**:4-5, 7-19; **II**:6, 14, 19, 21, 24, 33, 36, 39-40, 42, 48, 51, 56, 60, 63, 66, 68, 70, 72-73, 75, 77-78, 93, 96-101, 105-107, 109, 111-112, 115-116, 118-119, 121-130, 135, 138-139, 143-146, 148-150, 155-168, 174-176, 178, 182-183, 185, 190-191, 193-209, 219, 221, 223, 225, 233-238, 243, 247-248, 250-254, 263, 265-266, 270, 272, 274-275; **III**:3, 5, 9, 11-12, 15, 25, 27, 29, 31, 33, 35, 41, 43, 48, 50, 52, 58, 60, 63, 65, 67, 69, 71, 73, 75, 77, 79, 85, 87, 91, 95, 97, 99, 102, 104, 110, 112, 119, 122, 125, 129, 131-132, 136, 140, 146, 150-151, 153-155, 157-160, 162, 167, 169, 171, 175, 177, 180, 186, 190, 192, 194-195, 197, 200, 204, 206, 212, 214, 216, 218, 220, 223, 226, 229, 232, 235, 245, 247, 249, 251, 255, 257, 264, 271, 273, 282, 284, 286, 288, 290, 294, 296, 298, 300, 302
- Containment structures (RETR-CTMNT-001), **IA**:4, 11; **II**:94-103, 105-107, 109-117, 119-130; **III**:119-120
- Continuous air monitoring (CHAR 59-1N), **IA**:3, 9; **II**:4; **III**:39, 76
- Controlled air incineration (THRM/PHYS TI-01), **IA**:6, 13; **II**:231, 243, 245, 257; **III**:304
- Corrosives, **IB**:8, 11-12, 17, 19, 22, 29; **II**:24, 29, 51-52, 56, 64, 100, 103, 116, 118, 123, 148, 151, 178-179, 185, 194, 225, 227, 238-239, 243, 247, 272; **III**:3, 5, 9, 11, 15, 25, 27, 29, 31, 33, 35, 41, 50, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 102, 104, 110, 192, 218, 220, 226, 235, 249, 251, 288, 290, 294, 296
- CPP-01, **IB**:13; **II**:42, 112, 168, 236; **III**:11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102,

219-222, 104, 112, 119, 122, 129, 146, 177, 214, 220, 229, 245, 290

1, 5, 7, 9, 41, 50, 79, 85, 122, 167, 218, 245, 279, 300,

ICH-

9, 1:15

I:102, 5, 304,

7-19; 48, 51, 8, 93, 16, 118-148-150, 190-191, 243, 272, 29, 31, 65, 67, 97, 99, 131-157-186, 212, 235, 273, 3, 300,

1), IA:4, 130;

IA:3, 9;

I-01), 34

I:24, 29, 148, 239, 27, 29, 71, 77, 218, 4, 296

11, 29, 97, 102,

133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000

153, 157, 159, 177, 216, 223, 232, 247, 271, 290

CPP-19, **IB:**16; **II:**73, 127, 204, 251; **III:**11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 110, 112, 119, 129, 146, 150, 153, 157, 159, 177, 214, 220, 229, 245, 271, 290

CPP-22, **IB:**16; **II:**75, 128, 205, 252, 275; **III:**11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 146, 150, 153, 157, 159, 177, 216, 223, 232, 245, 271, 290

CPP-26, **IB:**9; **II:**17, 97, 141, 222, 265; **III:**3, 5, 11, 25, 27, 29, 35, 41, 43, 50, 52, 67, 69, 71, 77, 85, 87, 91, 97, 112, 119, 122, 129, 136, 140, 146, 169, 192, 214, 220, 229, 245

CPP-27, **IB:**11; **II:**24, 100, 148, 225; **III:**3, 5, 11, 25, 27, 29, 33, 35, 41, 50, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 192, 218, 226, 235, 249, 267, 279, 290, 294, 298

CPP-28, **IB:**9; **II:**19, 97, 143, 223; **III:**3, 5, 11, 25, 27, 29, 35, 41, 50, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 146, 150, 153, 157, 159, 180, 192, 216, 223, 232, 245, 290

CPP-29, **IB:**12; **II:**61, 121, 191; **III:**11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 112, 119, 122, 129, 136, 140, 146, 214, 220, 229, 245

CPP-31, **IB:**10; **II:**21, 98, 145, 223, 266; **III:**3, 5, 25, 27, 41, 50, 77, 91, 102, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 192, 216, 223, 232, 247, 267, 279, 290, 294, 298

CPP-35, **IB:**12; **II:**63, 122, 193, 247; **III:**11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 110, 112, 122, 129, 146, 150, 153, 157, 159, 180, 216, 223, 232, 290

CPP-36, **IB:**12; **II:**64, 123, 194, 247; **III:**3, 5, 9, 11, 15, 25, 27, 29, 31, 35, 41, 50, 52, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 112, 119, 146, 153, 218, 226, 235, 249, 267, 296

CPP-39, **IB:**19; **II:**29, 103, 151, 227; **III:**33, 67, 119, 122, 129, 136, 140, 146, 290

CPP-45, **IB:**17; **II:**56, 118, 185, 243, 272; **III:**3, 33, 67, 122, 129, 159, 251, 290

CPP-48, **IB:**19; **II:**51, 116, 178, 238; **III:**33, 67, 119, 122, 129, 146, 194, 294, 296

CPP-58, **IB:**17; **II:**78, 129, 208, 253; **III:**11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 112, 119, 122, 129, 146, 150, 153, 157, 177, 216, 223, 232, 247, 271, 290

CPP-69, **IB**: 16; **II**: 26, 101, 150, 226; **III**: 11, 67, 87, 97, 119, 177, 237, 241, 274, 284, 308

CPP-79, **IB**: 10; **II**: 22, 99, 147, 224; **III**: 3, 5, 11, 25, 27, 29, 35, 41, 43, 50, 52, 67, 69, 71, 77, 85, 87, 91, 97, 112, 119, 122, 146, 150, 153, 157, 159, 180, 214, 220, 245, 284, 290

CPP-80, **IB**: 18; **II**: 80, 130, 209, 254; **III**: 11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 180, 214, 220, 229, 245, 271, 290

D

Database management for large data collections (CHAR 72-IN), **IA**: 3, 9; **II**: 5; **III**: 54

Debris (waste form), **I**: 3, 7, 9, 17; **IB**: 3-5, 21-22, 27, 29; **II**: 6, 30, 36, 53, 87, 93, 104, 109, 117, 132, 135, 138-140, 143-146, 148-150, 152, 155-167, 174-176, 182-183, 190-191, 193-209, 215, 219, 221, 224-225, 228, 230, 232-233, 240-242, 247, 258-259, 263, 271, 276; **III**: 106, 108, 154, 160, 216, 218, 223, 226, 232, 235, 237, 239, 247, 249, 253, 259, 268, 273, 282, 286-288, 294, 296, 298, 304, 306, 308, 312

Diesel fuel, **IB**: 6, 21; **II**: 56, 58, 118-119, 184, 187, 242, 244, 272-273; **III**: 11, 43, 52, 67, 73, 99, 119, 122, 129, 136, 140, 146, 186, 253, 255, 259, 292, 294, 298, 308, 310

Dilute nitric acid wash (BICH-020), **IA**: 6, 11; **II**: 143, 145-146, 150, 155, 157, 162, 186; **III**: 192, 208, 210

Dilute nitric acid wash - lead (BICH-035), **IA**: 6, 11; **II**: 162; **III**: 210

Direct biological leaching (BICH-I-DBL, -DBL2, -DBL2B), **IA**: 5, 11; **II**: 135, 138, 141, 143, 145, 147, 149, 153-154, 156-157, 159, 161, 164, 167-168, 170, 172-173, 175, 177, 179-180, 182, 185, 190, 192-194, 196, 198-199, 201, 203-204, 206, 208, 210; **III**: 220, 223, 226

Direct-sampling ion trap mass spectrometry (CHAR 90-IN), **IA**: 3, 9; **II**: 30-31, 41, 54, 59, 85-89; **III**: 75-76

E

Electrical and electromagnetic (EM) methods (CHAR 125-IN), **IA**: 3, 9; **II**: 7-8, 10, 12-13, 15, 21, 26-27, 29, 37, 40, 43, 45-46, 48-49, 55, 61-62, 64, 67, 69, 72-73, 75-76, 78-79, 81, 83-84, 87; **III**: 104

Electron diffraction (ED, SAED, LEED) (CHAR 37-IN), **IA**: 3, 9; **II**: 9-10, 12, 14-15, 18, 20, 22-23, 25, 38, 41, 51, 54, 65; **III**: 27

Electron spectroscopy for chemical analysis (ESCA) (CHAR 1-IN), **IA**: 3, 9; **II**: 8, 10, 12, 14, 18, 20-21, 23, 25, 38, 41, 51, 53-54, 57, 65; **III**: 3

Europium-152, **IB**: 5; **II**: 7, 9, 11, 94-95, 137, 219-220

Europium-154, **IB**: 5, 7, 12; **II**: 7, 9, 11-12, 14-15, 64, 94-96, 123, 137-138, 140, 194, 219-222, 247, 264-265; **III**: 3, 5, 9, 11, 15, 17, 23, 25, 27, 29, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 101-102, 104, 110, 119, 122, 129, 136, 140, 146, 150, 153, 159, 162, 188, 190, 212, 216, 218, 223, 226, 232, 235, 237, 243, 247, 249, 279, 284, 286, 288, 296, 298, 304

Europium-155, **IB**: 5; **II**: 7, 9, 11, 94-95, 137, 219-220

Evaporation (THRM/PHYS PE-01), **IA**: 6, 13; **IB**: 22; **II**: 52, 117, 180, 222, 226, 239; **III**: 274

Externally-fired roaster (XTRAX) (THRM/PHYS TD-04), **IA**: 6, 13; **II**: 220, 223, 225, 228-230, 233, 242, 244-245, 258-259; **III**: 298

F

Fiber optic camera systems (CHAR 122-IN), **IA**: 3, 9; **II**: 16; **III**: 101

Fiber optic chemical sensors (CHAR 25-IN), **IA**: 3, 9; **II**: 16; **III**: 17

Floor (waste form), **IB**: 6, 15; **II**: 69, 125, 199, 249; **III**: 3, 5, 11, 25, 27, 35, 41, 50, 67, 69, 71, 77, 85, 87, 91, 96-97, 102, 104, 110, 112, 151, 177, 216, 220, 232, 247, 282, 284, 286, 290

Fluorescence (CHAR 92-IN), **IA**: 3, 9; **II**: 8, 10, 12-13, 15-16, 19-20, 22, 24-25, 30, 32, 38, 51, 55, 66, 83-84, 86-87, 89; **III**: 9, 77, 79

Fluorides, **IB**: 5; **II**: 7, 9, 11, 94-95, 137, 219-220, 222, 224-225, 249; **III**: 4, 45, 222, 225, 228, 231, 234, 236, 238, 240, 242, 244, 251, 276, 279, 300, 302

Fuel end boxes, **IB**: 27; **II**: 53, 117, 182, 240, 271; **III**: 3, 5, 7, 11, 25, 27, 29, 35, 41, 50, 67, 69, 73, 75, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 204, 216, 223, 232, 257, 282, 284, 286, 294, 296, 300, 302, 306, 308, 312

Fuel oil, **IB**: 20-21, 24; **II**: 34, 58, 107, 119, 160, 188, 230, 244; **III**: 9, 11, 15, 31, 52, 60, 63, 65, 67, 79, 122, 129, 162, 195, 253, 255, 259, 276, 292, 294, 296, 304, 306, 310

G

Gas chromatography (CHAR 1-IN), **I**: 59, 83, 24, 26, 56, 58, 99, 11

Gas chromatography (CHAR 1-IN), **I**: 59, 83

Gravel (waste form), **I**: 186, 200, 255, 2

Ground-penetrating radar (CHAR 1-IN), **I**: 40, 42, 73, 75

H

Hadamard transform (CHAR 1-IN), **I**: 1

Hot nitrogen (CHAR 1-IN), **I**: 18

Hydraulic fracturing (CHAR 1-IN), **I**: 111-112

Hydraulic fracturing (CHAR 1-IN), **I**: 111-112

Hydrocarbon (CHAR 1-IN), **I**: 152, 247, 263, 63, 64, 140, 294, 2

Hydrocarbon (CHAR 1-IN), **I**: 152, 247, 263, 63, 64, 140, 294, 2

Hydrofluoric acid (CHAR 1-IN), **I**: 151, 251, 2

I

Immunoassay (CHAR 1-IN), **I**: 81

In situ auger (CHAR 1-IN), **I**: 6

In situ measurement (CHAR 1-IN), **I**: 51-IN, 20-21, 49-50, 74, 76

In situ passive (CHAR 1-IN), **I**: 9; **II**: 2

G

Gas chromatography (GID, IC, TC) (CHAR 100-IN), **IA**:3, 9; **II**:26, 29-32, 41-42, 51, 54, 56-59, 85, 87-89; **III**:4, 6, 10, 12-13, 18-19, 21, 24, 26, 28, 30, 32-34, 38-39, 42-43, 51, 53-54, 56, 58, 61, 64, 66, 68, 70, 73, 80, 83, 92, 96, 99, 115

Gas chromatography--mass spectroscopy (GC-MS) (CHAR 88-IN), **IA**:3, 9; **II**:30-31, 41, 54, 56-59, 85, 87-89; **III**:73

Gravel (waste form), **I**:15; **IB**:12, 21; **II**:57, 118, 186, 243; **III**:67, 81, 83, 119, 122, 129, 202, 255, 259, 276, 294, 298, 308, 312

Ground-penetrating radar (CHAR 124-IN), **IA**:3, 9; **II**:7-8, 10-11, 13, 15, 20, 22, 25, 27, 29, 37, 40, 43, 45-46, 48-49, 55, 61-62, 64, 67, 69, 71, 73, 75-76, 78-79, 81, 83-84, 87; **III**:102

H

Hadamard masking for spatial resolution (CHAR 28-IN), **IA**:3, 9; **II**:4; **III**:21

Hot nitrogen stripping (BICH-031), **IA**:6, 11; **II**:183; **III**:204-205

Hydraulic oil, **IB**:5; **II**:94-95, 219-220

Hydraulic-powered shear attachment (RETR-SR-001), **IA**:4, 11; **II**:93, 96, 98-101, 106, 109, 111-112, 115, 122, 124-128, 130; **III**:153

Hydrocarbons, **IB**:3-4; **II**:31-32, 42, 56, 58, 104, 152, 154, 223, 225, 228-231, 238, 243-245, 247, 257, 267; **III**:9, 11, 15, 31, 33, 48, 52, 60, 63, 65, 67, 73, 75, 79, 95, 100, 119, 122, 136, 140, 146, 208, 214, 220, 229, 254, 257, 288, 294, 296, 298, 300, 302-303

Hydrofluoric acid, **IB**:17, 19; **II**:29, 56, 103, 118, 151, 185, 227, 243, 272; **III**:33, 67, 200, 220, 251, 294, 296

I

Immunoassay PCB (CHAR 99-IN), **IA**:3, 9; **II**:57; **III**:81

In situ auger injection (THRM/PHYS PSS-03), **IA**:6, 13; **II**:233, 239; **III**:288

In situ measurement of beta gamma emitters (CHAR 51-IN), **IA**:3, 9; **II**:3, 6, 8-9, 11, 13, 16, 18, 20-21, 23, 25, 27-28, 36, 38-39, 43-44, 46-47, 49-50, 52-54, 60, 62-63, 65, 67-68, 70-71, 73-74, 76-77, 79-80; **III**:35

In situ passive monitors - surface contamination by weak beta radionuclides (CHAR 102-IN), **IA**:3, 9; **II**:6, 8-9, 11, 13, 19-20, 23, 25, 27, 29, 36,

38-39, 43-44, 46-47, 49, 51, 54, 60, 62-63, 65, 67-68, 70-71, 73-74, 76-77, 79-80; **III**:85

Indirect biological leaching (BICH-I-IBL, -IBL2, -IBL2B), **IA**:5, 11; **II**:136, 139, 142, 144, 146-147, 149, 153, 155-156, 158, 160, 162, 164, 167, 169-170, 172, 174, 176, 178-179, 181, 183, 186, 191-193, 195-196, 198, 200-201, 203, 205, 207, 209-210; **III**:229, 232, 235

Indirectly heated screw conveyor (THRM/PHYS TD-06), **IA**:6, 13; **II**:228-229, 235, 240, 243; **III**:300

Inductively-coupled plasma mass spectroscopy (ICP-MS) (CHAR 78-IN), **IA**:3, 9; **II**:6, 17, 19, 24, 27-28, 30-31, 36, 39, 41-42, 44, 46-47, 49, 53, 60, 63, 66-68, 71-72, 74-75, 77, 79, 85-86, 88; **III**:65

Inductively-coupled plasma spectroscopy (ICP) (CHAR 77-IN), **IA**:3, 9; **II**:1, 30-31, 41, 57, 66, 85-86, 88; **III**:63, 66

Industrial boiler (THRM/PHYS TI-05), **IA**:6, 13; **II**:244-245; **III**:310

Infrared analysis of wastes (CHAR 136-IN), **IA**:3, 9; **II**:83-84; **III**:115

Ion chromatography (IC) (CHAR 50-IN), **IA**:3, 9; **II**:26, 29-30, 32, 51, 56-57; **III**:33, 83

Isotopic dilution mass spectrometry (IDMS) (CHAR 48-IN), **IA**:3, 9; **II**:16, 31, 41, 85-86, 88; **III**:31

K

Kerosene, **IB**:11; **II**:40, 112, 166, 235; **III**:3, 5, 9, 11, 15, 25, 27, 31, 33, 41, 48, 50, 52, 60, 63, 65, 67, 73, 75, 77, 79, 91, 95, 99, 102, 104, 216, 220, 232, 257, 271, 300, 302

L

Laboratory chemicals, **IB**:3; **II**:30, 104, 152, 228; **III**:9, 11, 15, 31, 33, 48, 52, 60, 63, 65, 67, 73, 75, 79, 95, 119, 122, 129, 146, 162, 253, 255, 259, 282, 298, 300, 302

Landfarming (BICH-O-LFM), **IA**:5, 11; **II**:152, 161, 184, 188-189, 213; **III**:253

Laser ablation--diagnosing metals and radionuclides (CHAR 86-IN), **IA**:3, 9; **II**:6, 17, 19, 22, 24, 27-28, 36, 39, 42, 44, 46-47, 49-50, 60, 63-64, 67-68, 70-72, 74-75, 77, 79; **III**:71

Laser ablation--inductively-coupled plasma atomic emission spectroscopy (CHAR 111-IN), **IA**:3, 9; **II**:6, 17, 19, 22, 24, 27-28, 36, 39, 42, 44, 46-47, 49-50, 60, 63-64, 67-68, 70-72, 74-75, 77, 79

Laser scattering particle size analysis (CHAR 26-IN),
IA: 3, 9; **II:** 4; **III:** 19

Lead, **I:** 4, 8; **IB:** 3-5, 20; **II:** 7, 9, 11, 31-32, 34, 57, 94-95, 104-105, 107-108, 118, 137, 152, 154-155, 161-162, 166, 183, 185-189, 214, 219-220, 228-229, 232, 243, 267; **III:** 4, 6-7, 9-13, 15, 18-19, 21, 24, 26, 28, 30-34, 38-39, 42-43, 48, 51-54, 56, 58, 60-61, 63-68, 70, 73, 75, 79-80, 95-96, 119, 122, 129, 136, 140, 144, 146, 151, 192, 208, 210, 212, 214, 216, 218, 220, 223, 226, 229, 232, 235, 249, 257, 267, 271, 281-282, 284, 286, 288, 290, 294, 296, 298, 300, 302, 306

Lead oxide, **IB:** 20; **II:** 34, 107, 161, 232; **III:** 9, 11, 31, 60, 63, 65, 67, 79, 122, 129, 210, 212, 216, 223, 232, 281-282, 284, 286

Liquid (waste form), **IB:** 4-5, 7-8, 10, 16-17, 21, 24, 27, 29; **II:** 3-4, 7, 9-12, 14-16, 18, 20-21, 23-27, 29, 37-40, 43, 45-46, 48-49, 51-52, 55-56, 61-62, 64-65, 67, 69, 72-73, 75-76, 78-79, 81-82, 85, 87, 94-96, 98, 100-101, 103, 111, 116, 118, 120, 123, 132, 137, 140, 145, 148, 150-152, 154, 158, 160, 162-163, 165-166, 178, 179, 183-189, 194, 213-215, 219-223, 225-227, 230-231, 234-235, 237-239, 241-248, 250-254, 257-259, 266, 272, 276; **III:** 3, 5, 7, 10-11, 16-17, 19, 21, 23, 25, 27, 32, 37, 39, 48, 50-51, 61, 64, 66-67, 73, 75, 80, 87, 97, 112-113, 115, 122, 129, 162, 168, 170-171, 173, 176-178, 181-182, 184, 188, 190, 192, 197-198, 201, 208, 210, 212, 237, 239, 241, 251, 255, 257, 269, 274, 276-278, 284-286, 293, 306, 308

Liquid injection combustor (THRM/PHYS TI-04),
IA: 6, 13; **II:** 226, 244-245, 257-259; **III:** 308

Liquid scintillation counting (CHAR 129-IN), **IA:** 3, 9; **II:** 3-4, 7, 9-10, 12, 14, 16, 18, 20, 23, 25-27, 29, 37-38, 40, 43, 45-46, 48-49, 51-52, 55, 61-62, 64-65, 67, 69, 72-73, 75-76, 78-79, 81-82; **III:** 23, 112-113

Lithium, **II:** 83-84, 131, 213, 257; **III:** 102, 104, 106, 108, 110, 253, 255, 259, 296, 304, 308, 311-312

LOFT-01, **IB:** 6; **II:** 56, 118, 184, 242, 272; **III:** 52, 67, 73, 99, 122, 129, 136, 140, 186, 253, 255, 259, 290, 292

LOFT-02, **IB:** 4; **II:** 32, 105, 155, 229, 267; **III:** 11, 31, 52, 67, 119, 122, 129, 136, 140, 144, 192, 218, 226, 235, 249, 267, 284, 290, 298, 300, 302

M

Magnetics (CHAR 128-IN), **IA:** 3, 9; **II:** 7-8, 10-11, 13, 15, 21, 25, 27, 29, 37, 40, 43, 45-46, 48-49, 55, 61-62, 64, 67, 69, 71, 73, 75-76, 78-79, 81, 83-84, 87; **III:** 110

Manganese (Mn-54), **IB:** 5, 7; **II:** 7, 9, 11, 14-15, 94-96, 135, 137-138, 140-141, 143, 145, 147, 149, 153-154, 156-157, 159, 161, 164, 167-170, 172-173, 175, 177, 179-180, 182, 185, 190, 192-194, 196, 198-199, 201, 203-204, 206, 208, 210, 219-222, 265; **III:** 3, 5, 9, 11, 15, 17, 23, 25, 27, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 77, 79, 87, 91, 97, 101-102, 104, 110, 119, 122, 126, 129, 146, 150, 153, 155, 159, 161-162, 188, 190, 205, 212, 216, 220, 223, 226, 232, 237, 243, 279, 284, 286

Manual vapor vacuum (RETR-VAC-001), **IA:** 4, 11; **II:** 104, 120; **III:** 162

Manually operated backhoe (RETR-ME-003), **IA:** 4, 11; **II:** 93-119, 121-130, 132; **III:** 130

Manually operated concrete saw (RETR-SR-002),
IA: 4, 11; **II:** 98-101, 106-107, 109, 111-112, 115, 122, 124-128, 130; **III:** 157

Manually operated dozer (RETR-ME-005), **IA:** 4, 11; **II:** 93-94, 97-98, 100-103, 105-107, 110, 113-114, 116, 118-119, 121, 129-130, 132; **III:** 140

Manually operated excavator (RETR-ME-001), **IA:** 4, 11; **II:** 93-95, 97-110, 112-119, 121-126, 128-130, 132; **III:** 123

Manually operated hydraulic ram (RETR-SR-003),
IA: 4, 11; **II:** 93, 96, 98-101, 106-107, 109, 111-112, 115, 122, 124-128, 130; **III:** 159

Manually operated motor grader (RETR-ME-004),
IA: 5, 11; **II:** 94, 97-98, 100, 102-103, 105, 110, 114, 116, 118, 120-121, 129-130, 132; **III:** 136

Manually operated scabbler (RETR-SCA-001), **IA:** 5, 11; **II:** 93, 96, 98-99, 101, 106, 109, 111-112, 115, 122-129; **III:** 150

Manually operated trencher (RETR-ME-006), **IA:** 5, 11; **II:** 105; **III:** 144

Membrane technology for sample collection and concentration (CHAR 55-IN), **IA:** 3, 9; **II:** 16; **III:** 37

Mercuric nitrate, **IB:** 9-12; **II:** 21, 24, 64, 98, 100, 123, 145, 148, 194, 220, 223, 225, 233, 247, 266; **III:** 3, 5, 9, 11, 15, 25, 27, 29, 31, 33, 35, 41, 50, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 102, 104, 119, 122, 129, 136, 140, 150, 153, 157, 192, 216, 218, 223, 226, 232, 235, 247, 249, 279, 288, 290, 294, 296, 298

Mercury, **I**:8; **IB**:4-7, 20-21; **II**:7, 9, 11, 15, 17, 21, 24, 30-33, 37, 41, 56, 64, 66, 85-86, 88, 94-96, 100, 105, 107, 110, 118, 123, 132, 137, 140, 145, 148-150, 154-156, 160, 164-165, 181, 184, 190, 194-195, 214-215, 219-225, 229-230, 233, 242, 247, 258-259, 266-269, 276; **III**:3-7, 9-13, 15-19, 21, 23-32, 34-35, 37-39, 41-43, 48, 50-54, 56, 58, 60-61, 63-71, 73, 75, 77, 79-80, 85, 87, 91, 95-97, 99, 101, 119, 122, 129, 136, 140, 144, 146, 173, 176, 178, 182, 184, 188, 191-193, 197-198, 200-201, 205, 209, 211-212, 218, 226, 235, 237, 243, 247, 249, 267-268, 280-282, 284, 286, 288, 290, 298-300, 302, 308, 312

Metallographic sample preparation (CHAR 67-IN), **IA**:4, 9; **II**:6, 14, 18-19, 21-22, 24, 26, 28, 36-37, 39-40, 42, 44-45, 47-48, 50, 53, 60, 63, 65-66, 68, 70, 72-73, 75, 77-78, 80; **III**:50

Metals, **I**:3, 5, 8-9, 11, 13; **IB**:3-6, 8, 11-12, 15, 17, 20, 22, 27, 29; **II**:6-8, 10-13, 15, 21, 24-25, 27, 29-34, 36-37, 40, 42-43, 45-46, 48-49, 52-53, 55-57, 61-62, 64, 67, 69, 71, 73, 75-76, 78-79, 81, 83-84, 87, 93, 95-96, 98-101, 104-109, 111-112, 115, 117-118, 122-128, 130-131, 135-136, 138-150, 152-186, 190-210, 213, 219-230, 232-243, 247-255, 257, 263-264, 267, 271; **III**:3, 5, 7, 9, 11, 15, 25, 27, 29, 31, 33, 35, 41, 48, 50, 52, 60-61, 63-67, 69, 71, 73, 75, 77, 79-80, 85, 87, 91, 95, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 150, 153, 162, 167-171, 173, 175-178, 180-181, 188, 191-193, 197-198, 200-201, 204-206, 208-211, 216, 218, 220, 222-227, 229-230, 232-233, 235-251, 253, 255-259, 263-264, 267, 269, 271, 273, 279-282, 284, 286-288, 290-291, 294, 296, 298-300, 302, 304, 306, 308, 311-312

Methyl chloroform, **IB**:5; **II**:7, 9, 11, 94-95, 137

Microgravity methods (CHAR 127-IN), **IA**:4, 9; **II**:83-84, 87; **III**:108

Microwave digestion (CHAR 19-IN), **IA**:4, 9; **II**:6-7, 9, 11, 13, 16, 18-19, 22, 24, 27-28, 30-37, 39-40, 43-44, 46-47, 49, 52-54, 56-57, 60-61, 63-64, 67-68, 71-72, 74, 76-77, 79-80, 85-86, 88; **III**:11

Mineral oil, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Minimum additive waste stabilization (MAWS) (THRM/PHYS PF-02), **IA**:6, 13; **II**:222, 224-225, 249; **III**:279-280

Mixed waste, **I**:12, 16-18; **IB**:3, 6, 8, 27; **II**:219-220, 223, 225, 231, 233, 240-243, 246, 249, 257-259; **III**:279, 281-282, 285, 290, 309-310, 318

Multi-angle drilling (CHAR 64-IN), **IA**:4, 9; **II**:17, 22; **III**:43-44

N

Nal GE gamma spectroscopy (CHAR 106-IN), **IA**:4, 9; **II**:4, 7-9, 11, 13, 16, 19-20, 23, 25-27, 29, 37-38, 40, 43, 45-46, 48-49, 51, 54, 61-62, 64-65, 67, 69-71, 73-74, 76, 78-80

Neutron Activation (semi lab) (CHAR 107-IN), **IA**:4, 9; **II**:3; **III**:89

Niobium (Nb-97), **IB**:7; **II**:14-15, 96, 138, 140, 221-222, 265; **III**:3, 5, 9, 11, 15, 17, 23, 25, 27, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 77, 79, 87, 91, 97, 101-102, 104, 110, 119, 122, 129, 146, 150, 153, 159, 162, 188, 190, 212, 216, 223, 232, 237, 243, 247, 279, 284, 286

Nitric acid, **IB**:9-12, 17, 19; **II**:21, 24, 51, 56, 64, 98, 100, 116, 118, 123, 139, 143, 145-146, 148, 150, 154-155, 157, 162, 178, 185-186, 194, 223, 225, 238, 243, 247, 266, 272; **III**:3, 5, 9, 11, 15, 25, 27, 29, 31, 33, 35, 41, 50, 60, 63, 65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 102, 104, 119, 122, 129, 136, 140, 150, 153, 157, 159, 173, 182, 184, 190, 192, 194, 197, 204, 208, 210, 216, 218, 220, 223, 226, 232, 235, 247, 249, 251, 279, 288, 290, 294, 296, 298

Nitric acid/EDTA wash (BICH-017A), **IA**:6, 11; **II**:139; **III**:190

O

Oc9 pump oil, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Optimization of sampling designs (CHAR 71-IN), **IA**:4, 9; **II**:3-4, 6-7, 9, 11-12, 15, 17, 22, 26, 28, 30-34, 36-37, 39, 42, 44-45, 47-48, 50, 52-53, 56-58, 60-61, 63-64, 66, 68-70, 72-73, 75, 77-78, 80, 85-86, 88; **III**:52

Ordinance (waste form), **IB**:29; **II**:83-84, 131, 213, 257; **III**:9, 60, 79, 95, 102, 104, 106, 108, 110, 115, 146-147, 253, 255, 259, 292, 296, 304, 308, 311-312

Organic vapor monitoring (CHAR 5-IN), **IA**:4, 9; **II**:55, 57, 59, 85-89; **III**:7

Organics, **I**:12; **IB**:3-6, 8, 20-21, 24, 27; **II**:12, 30-32, 34, 41-42, 54, 56-59, 85-89, 95, 104, 107, 118-119, 135-136, 138-139, 141-147, 149, 152-162, 164-170, 172-196, 198-201, 203-210, 213-215, 219-222, 224-225, 227-230, 240-245, 249, 257, 264, 267, 272; **III**:3, 5, 7, 9, 11, 15, 25, 27, 29, 31, 33, 41, 43, 48, 50, 52, 60, 63, 65, 67, 73, 75-77, 79, 81, 83, 87, 91, 95, 97, 99, 104, 110, 112, 119, 122, 129, 136, 140, 146,

162, 186, 194-195, 202, 208, 214-215, 217, 219-221, 224, 226-227, 229-230, 233, 235, 253, 255, 257, 259, 276, 279-280, 282, 284, 286, 288, 290-292, 294, 296, 298, 300, 302, 304, 306, 308, 310-311		
OU 1-01, IB:3	OU 2-07, IB:6	OU 3-12 151, 50, 5 112, 220,
OU 1-02, IB:3	OU 2-08, IB:8; II:39-40, 111, 165-166, 234-235; III:11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 112, 119, 129, 146, 150, 153, 157, 159, 239, 255, 271, 290	OU 3-13 227, 140,
OU 1-03, IB:3; II:30-32, 104-105, 152-155, 228-229, 267; III:9, 11, 15, 31, 33, 48, 52, 60, 63, 65, 67, 73, 75, 79, 95, 99, 122, 129, 146, 162, 208, 214, 220, 229, 253, 255, 257, 259, 282, 284, 290, 298, 300, 302, 317, 319	OU 2-09, IB:4, 7	OU 4-01
OU 1-04, IB:4; II:32-33, 105, 155-157, 229-230, 267-268; III:11, 31, 52, 67, 119, 122, 129, 136, 140, 144, 192, 218, 226, 235, 249, 267, 284, 290, 298, 300, 302, 317, 319	OU 2-10, IB:6	OU 4-02
OU 1-05, I:3; IB:4; II:6-14, 36-37, 93-95, 109-110, 135-138, 163, 219-221, 233, 263-264; III:3, 5, 11, 25, 27, 29, 35, 41, 50, 52, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 167, 212, 214, 220, 229, 245, 263, 267, 269, 271, 273, 284, 290, 298, 312, 317, 319	OU 2-11, IB:6	OU 4-03
OU 1-06, IB:6, 8; II:37-38, 56, 110, 118, 164-165, 184, 233-234, 242, 269, 272; III:3, 5, 11, 15, 25, 27, 29, 35, 41, 50, 52, 67, 69, 71, 73, 77, 85, 87, 91, 97, 99, 112, 119, 122, 129, 136, 140, 146, 173, 186, 197, 218, 226, 235, 249, 253, 255, 259, 267, 281, 288, 290, 292, 298, 317, 319	OU 3-01, IB:8	OU 4-04
OU 1-07A, IB:3	OU 3-02, IB:8	OU 4-05 268; 162, 298,
OU 1-07B, IB:6	OU 3-03, IB:8	OU 4-06 161- 60, 6 216, 290,
OU 1-08, IB:3	OU 3-04, IB:8	OU 4-07
OU 1-09, IB:3	OU 3-05, IB:8	OU 4-08
OU 1-10, IB:3-4, 6; II:6, 30-32, 56, 93, 104-105, 118, 135, 152, 154-155, 184, 219, 228-229, 242, 263, 267, 272; III:95	OU 3-06, IB:8	OU 4-09 245, 186, 304,
OU 2-01, IB:6	OU 3-07, IB:8; II:17-24, 82, 97-100, 141-148, 212, 222-224, 256, 265-266; III:3, 5, 11, 25, 27, 29, 35, 41, 43, 50, 52, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 169, 180, 192, 214, 216, 220, 223, 229, 232, 245, 247, 267, 279, 284, 290, 294, 298, 317, 319	OU 4-10
OU 2-02, IB:6	OU 3-08, IB:10; II:24-26, 40-42, 60-66, 100-101, 112, 121-123, 148-150, 166-167, 190-195, 225, 235, 247; III:3, 5, 9, 11, 15, 25, 27, 29, 31, 33, 35, 41, 48, 50, 52, 60, 63, 65, 67, 69, 71, 73, 75, 77, 79, 85, 87, 91, 97, 99, 102, 104, 110, 112, 114, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 180, 192, 206, 214, 216, 218, 220, 223, 226, 229, 232, 235, 245, 247, 249, 257, 267, 279, 290, 294, 296, 298, 300, 302	OU 4-11
OU 2-03, IB:6	OU 3-09, IB:12; II:26, 42-51, 66-78, 101, 112-116, 123-129, 150-151, 168-178, 195-207, 226, 236-238, 247-253, 269-270, 274-275; III:3, 5, 11, 25, 27, 29, 35, 41, 50, 52, 58, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 177, 180, 214, 216, 220, 223, 229, 232, 237, 241, 245, 247, 271, 274, 279, 282, 284, 290, 308, 317, 319	OU 4-12 276- 73, 7 129, 308,
OU 2-04, IB:6	OU 3-10, IB:8	OU 4-13
OU 2-05, IB:7; II:14-17, 96, 138-140, 221-222, 265; III:3, 5, 9, 11, 15, 17, 23, 25, 27, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 77, 79, 87, 91, 97, 101-102, 104, 110, 112, 119, 122, 129, 146, 150, 153, 159, 162, 188, 190, 212, 216, 223, 232, 237, 243, 247, 279, 284, 290, 317, 319	OU 3-11, IB:17; II:56-57, 78-79, 118, 129-130, 185, 208-209, 243, 253-254, 272-273; III:3, 11, 29, 33, 35, 41, 50, 52, 67, 69, 71, 85, 91, 97, 102, 104, 112, 119, 122, 129, 146, 150, 153, 157, 159, 177, 216, 223, 232, 247, 251, 271, 290, 317, 319	OU 5-01
OU 2-06, IB:6		OU 5-02
		OU 5-03
		OU 5-04
		OU 5-05
		OU 5-06
		OU 5-07
		OU 5-08
		OU 5-09
		OU 5-10

3, OU 3-12, **IB:** 18; **II:** 26-29, 80-81, 101-102, 130, 151, 209-211, 226, 254-255; **III:** 11, 29, 35, 41, 50, 52, 67, 69, 71, 85, 87, 91, 97, 102, 104, 112, 119, 122, 129, 136, 140, 146, 180, 214, 220, 229, 245, 290

OU 3-13, **IB:** 18; **II:** 29, 51, 103, 116, 151, 178, 227, 238-239; **III:** 33, 67, 119, 122, 129, 136, 140, 146, 194, 290, 294, 296

OU 4-01, **IB:** 19, 29

OU 4-02, **IB:** 19

OU 4-03, **IB:** 19

OU 4-04, **IB:** 19

OU 4-05, **IB:** 19; **II:** 33-34, 107, 160-161, 230-231, 268; **III:** 11, 31, 52, 67, 119, 122, 129, 140, 162, 173, 253, 255, 267, 276, 292, 294, 296, 298, 304, 306, 312, 317, 319

OU 4-06, **IB:** 19-20; **II:** 34-35, 57, 107-108, 118, 161-162, 185-186, 232, 243; **III:** 7, 11, 31, 52, 60, 63, 67, 73, 122, 129, 208, 210, 212, 214, 216, 220, 223, 229, 232, 257, 282, 284, 286, 290, 300, 302, 306

OU 4-07, **IB:** 19

OU 4-08, **IB:** 19

5, OU 4-09, **IB:** 20; **II:** 57-58, 118-119, 186-189, 243-245, 273; **III:** 52, 67, 73, 81, 83, 119, 122, 129, 186, 195, 202, 253, 255, 259, 276, 294, 298, 304, 308, 310, 312

OU 4-10, **IB:** 19

OU 4-11, **IB:** 19

6, OU 4-12, **IB:** 21; **II:** 85-89, 132, 214-215, 258-259, 276-277; **III:** 7, 9, 15, 31, 52, 60, 63, 65, 67, 73, 75, 79, 95, 102, 104, 106, 108, 110, 122, 129, 136, 140, 182, 184, 255, 257, 267, 298, 308, 312, 317, 319

OU 4-13, **IB:** 22

OU 5-01, **IB:** 22

OU 5-02, **IB:** 22

OU 5-03, **IB:** 22-23

OU 5-04, **IB:** 22

OU 5-05, **IB:** 22

OU 5-06, **IB:** 22

OU 5-07, **IB:** 22

OU 5-08, **IB:** 22

OU 5-09, **IB:** 22

OU 5-10, **IB:** 22

OU 5-12, **IB:** 22; **II:** 52-53, 116-117, 179-181, 239; **III:** 9, 11, 29, 31, 41, 50, 52, 65, 67, 69, 71, 91, 110, 112, 119, 122, 129, 146, 175, 200, 214, 220, 229, 245, 274, 288, 290

OU 5-13, **IB:** 22

OU 7-01, **IB:** 24; **II:** 53, 117

OU 7-02, **IB:** 24

OU 7-03, **IB:** 24; **II:** 53, 59, 117

OU 7-04, **IB:** 24

OU 7-05, **IB:** 24

OU 7-06, **IB:** 24

OU 7-07, **IB:** 24

OU 7-08, **IB:** 24; **II:** 59, 119-120, 189, 245-246; **III:** 7, 73, 75, 119, 122, 129, 136, 140, 146, 162, 255, 259, 284, 292, 298, 304, 308, 311-312

OU 7-09, **IB:** 24

OU 7-10, **IB:** 24

OU 7-11, **IB:** 24

OU 7-12, **IB:** 24

OU 7-13, **IB:** 24, 27; **II:** 53-55, 59, 117, 119, 182-183, 240-241, 271; **III:** 3, 5, 7, 11, 25, 27, 35, 41, 50, 67, 69, 73, 75, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 146, 204, 216, 223, 232, 282, 284, 286, 290, 300, 302, 306, 312, 317, 319

OU 7-14, **IB:** 27

OU 10-01, **IB:** 29

OU 10-02, **IB:** 29

OU 10-03, **IB:** 29; **II:** 83-84, 131, 213, 257; **III:** 60, 79, 102, 104, 106, 108, 110, 115, 146, 253, 255, 259, 292, 296, 304, 308, 312

OU 10-04, **IB:** 29

OU 10-05, **IB:** 29

P

Paint thinner, **IB:** 20-21; **II:** 57, 85, 87, 118, 132, 185, 214-215, 243, 258-259, 276; **III:** 7, 9, 11, 15, 31, 52, 60, 63, 65, 67, 73, 75, 79, 95, 119, 122, 129, 208, 214, 229, 255, 257, 284, 286, 290, 294, 296, 300, 302, 306, 308

PBF-08, **IB:** 22; **II:** 52, 116, 179, 239; **III:** 11, 29, 41, 50, 52, 69, 71, 91, 112, 119, 129, 146, 175, 214, 220, 229, 274, 290

Petroleum, **IB:** 6, 8, 20-21, 24; **II:** 5, 32, 34, 50, 56, 58, 69, 83-84, 87, 107, 118-119, 160, 184, 187-

188, 221-226, 229-231, 233-239, 241-244, 247-255, 257, 272-273; **III**:9, 11, 15, 31, 43, 52, 59-60, 63, 65, 67, 73, 79, 99-100, 108, 119, 122, 129, 136, 140, 146, 162, 186, 195, 253, 255, 259, 276, 290, 292, 294, 296, 298, 303-304, 306, 308, 310

Picric acid, **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 259, 296, 304, 308, 311-312

Plant uptake of metals/radionuclides (BICH-I-PUC, -PUC2, -PUC2B), **IA**:5, 11; **II**:136, 139, 142, 144, 146, 148, 150, 156, 165, 168-169, 171, 173-174, 176, 181, 190-191, 195, 197, 199-200, 202, 204-205, 208-209; **III**:245, 247, 249

Plutonium (Pu-239), **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220; **III**:119, 122, 129, 136, 140, 146, 284, 288, 298

Plutonium (Pu-240), **III**:119, 122, 129, 136, 140, 146, 284, 286, 288, 298

Plutonium, **IB**:9, 11, 27; **II**:17, 40, 53, 97, 112, 117, 141-142, 166, 182, 222, 235, 240, 265, 271; **III**:3, 5, 7, 9, 11, 15, 25, 27, 29, 31-33, 35, 41, 43, 48, 50, 52, 60, 63, 65, 67, 69, 71, 73, 75, 77, 79, 85, 87, 91, 95, 97, 99, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 150, 153, 157, 159, 169, 192, 204, 214, 216, 220, 223, 229, 232, 245, 257, 271, 282, 284, 286, 294, 296, 300, 302, 306, 308, 312

Polychlorinated biphenyls (PCBs), **I**:8; **IB**:8, 20-21; **II**:32, 42, 56-58, 118, 186-187, 219-226, 228-230, 233-243, 247-255, 257; **III**:8, 13, 18, 21, 24, 26, 30, 32, 38-39, 42-43, 53-54, 56, 58, 67-68, 70, 74, 76, 78, 81, 83, 99-100, 119, 202, 255, 259, 276-277, 290, 294, 298, 302-303, 308, 312

Polymer solidification (THRM/PHYS PSS-02), **IA**:6, 13; **II**:232, 241; **III**:286

Portable gamma-ray spectrometry (CHAR 112-IN), **IA**:4, 9; **II**:3-4, 7-9, 11, 13, 16, 19-20, 23, 25-27, 29, 37-38, 40, 43, 45-46, 48-49, 51, 54, 61-62, 64-65, 67, 69-71, 73-74, 76, 78-80; **III**:97

Proportional counting (CHAR 108-IN), **IA**:4, 9; **II**:3-4, 6-7, 9, 11, 13-14, 16, 18, 20-21, 23-24, 27-28, 36, 38-39, 43-44, 46-47, 49-50, 52-54, 60, 62-63, 65, 67-68, 70-71, 73-74, 76-77, 79-80; **III**:91

Punch cores (CHAR 83-IN), **IA**:4, 9; **II**:6, 17, 19, 22, 24, 27-29, 36-37, 39, 42, 44-45, 47, 49-50, 52-53, 60-61, 63-64, 66, 68-69, 71-72, 74-75, 77-78, 80; **III**:69

R

Radionuclides (see also listings for individual nuclides), **I**:16; **IB**:8-10, 17, 24; **II**:6, 8-9, 11, 13, 19-20, 23, 25, 27, 29, 36, 38-39, 43-44, 46-47, 49, 51, 54, 60, 62-63, 65, 67-68, 70-71, 73-74, 76-77, 79-80, 135-136, 138-139, 141-150, 153-162, 164-165, 167-183, 185-186, 190-210, 219-226, 229-230, 233-243, 247-255, 257; **III**:71, 85, 168, 170, 174, 176, 178, 181, 183, 185-186, 188, 190-191, 193, 198, 201-202, 205, 207, 209, 211-212, 215, 217, 219, 221, 224, 227, 229-230, 232-233, 235-236, 245-251, 256, 258, 286, 290, 311, 313

Radium (Ra-226), **I**:3; **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

RDX, **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 296, 304, 308, 311-312

Rocky Flats Plant fire waste, **IB**:27

Rotary kiln incineration (THRM/PHYS TI-02), **IA**:6, 13; **II**:230, 240, 243; **III**:306

Rotary kiln indirect (THRM/PHYS TD-03), **IA**:6, 13; **II**:231, 238, 247, 257; **III**:296

Rotary kiln-direct (THRM/PHYS TD-02), **IA**:6, 13; **II**:223, 225, 231, 238, 243-245; **III**:294

Ruthenium (Ru-106), **IB**:11, 17; **II**:60, 121, 190; **III**:3, 5, 11, 25, 27, 29, 35, 41, 50, 67, 69, 71, 77, 85, 87, 91, 97, 104, 216, 223, 232

RWMC-04, **IB**:27; **II**:53, 117, 182, 240, 271; **III**:3, 5, 7, 11, 25, 27, 35, 41, 50, 67, 69, 73, 75, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 146, 204, 216, 223, 232, 257, 282, 284, 286, 290, 306, 312

S

Sampling and mixing methods (CHAR 81-IN), **IA**:4, 9; **II**:6-7, 9, 11-12, 15, 17, 19, 22, 24, 26, 28-37, 39-40, 42, 44-45, 47-48, 50-53, 56-58, 60-61, 63-64, 66, 68-69, 71-72, 74-75, 77-78, 80, 85-88; **III**:68

Sand blasting (THRM/PHYS PB-03), **IA**:7, 13; **II**:219, 234-235, 237, 247-248, 250-254; **III**:273

Screening and sorting methods (THRM/PHYS PSR-01), **IA**:7, 13; **II**:228, 232, 240, 249; **III**:282

Secondary ion mass spectrometry (SIMS) (CHAR 135-IN), **IA**:4, 9; **II**:42; **III**:114

Seismic methods (refraction, profiling, reflection) (CHAR 126-IN), **IA**:4, 9; **II**:83-84, 87; **III**:106

S

S

S

S

Si

Si

Sc

Sc

Sc

- 1
3-9, 11,
3-44, 46-
5-71, 73-
41-150,
190-210,
257;
31, 183,
202,
221,
245-251,

4-95,

34, 106,
1-312

02), **IA**:6,

, **IA**:6,

IA:6, 13;
94
21, 190;
7, 69, 71,
2
271;
69, 73,
112, 119,
57, 282,

-IN), **IA**:4,
4, 26, 28-
36-58, 60-
77-78, 80,

7, 13;
254;

HYS PSR -
; **III**:282
(CHAR
(lection)
87; **III**:106
- Silver (Ag-110), **IB**:4, 7; **II**:14-15, 96, 138, 140,
221-222, 265; **III**:3, 5, 9, 11, 15, 17, 23, 25,
27, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 77,
79, 87, 91, 97, 101-102, 104, 110, 119, 122,
129, 146, 150, 153, 159, 162, 188, 190, 212,
216, 223, 232, 237, 243, 247, 279, 284, 286
- Sludge (waste form), **I**:9; **IB**:4-5, 8, 12, 15, 20-22,
27; **II**:7, 9, 11-12, 34, 39, 52, 59, 70, 86, 88,
94-96, 101, 107, 111, 116-117, 119-120, 126,
132, 137-138, 140, 150, 152, 154, 158, 160,
162, 165-166, 179, 183-189, 200, 213-215,
219-220, 230-231, 234, 239, 245, 250, 258-
259, 276; **III**:3, 5, 7, 9, 11, 15, 25, 27, 29, 31,
35, 52, 60, 63, 65, 67, 69, 71, 73, 75, 77, 79,
85, 87, 91, 95, 97, 112, 119, 122, 129, 136,
140, 146, 162, 171, 175, 182, 186, 190, 194-
195, 212, 214, 220-221, 224, 227, 229-230,
233, 236, 241, 243, 246, 248, 250-251, 253,
255, 257, 259, 274, 284, 286, 292, 294, 296,
298, 304, 306, 308, 312
- Slurry/liquid biodentrification (BICH-NO3-B), **IA**:5,
11; **II**:152, 161, 184-185, 188-189, 213;
III:251, 253
- Slurry/liquid bioremediation (BICH-O-SB, -SB2),
IA:5, 11; **II**:152, 154, 160, 165-166, 183-184,
186-189, 213-215; **III**:255, 257
- Small long-range alpha Detection (LRAD) (CHAR
65-IN), **IA**:4, 9; **II**:3; **III**:46
- Smokeless powder, **II**:83-84, 131, 213, 257;
III:102, 104, 106, 110, 253, 255, 259, 296,
304, 308, 311-312
- Sodium bicarbonate wash (BICH-023), **IA**:6, 11;
II:178; **III**:194
- Soil (waste form), **I**:3, 5, 7, 9-12, 14-15; **IB**:3-22,
27, 29; **II**:4, 6, 12, 14, 17, 19, 21-22, 24, 26,
28-34, 36-37, 39-40, 42, 44-45, 47-48, 50-53,
56-61, 63-64, 66, 68-70, 72-73, 75, 77-78, 80,
83, 93-107, 109-119, 121-131, 135-136, 138-
211, 213-215, 219-245, 247-255, 257, 263-277;
III:3, 5, 7, 9, 11-12, 15, 25, 27, 29, 31, 33, 35,
41, 43, 48, 50, 52, 58, 60, 63, 65, 67, 69, 71,
73, 75, 77, 79, 81, 83, 85, 87, 95, 97, 99-100,
102, 104, 106, 108, 112, 114, 119, 122, 124,
129-130, 136, 138, 140-142, 144, 146, 150,
153, 157, 159, 162, 167-171, 173, 175-178,
180-181, 184, 186, 188, 190, 192-195, 197-
198, 200-202, 204-210, 212, 214, 216, 218,
220-221, 223-224, 226-227, 229-230, 232-233,
235-236, 245-251, 253, 255, 257, 259, 263,
267, 269, 271, 276, 279-282, 284, 286, 288,
290-292, 294, 296, 298, 300-303, 306, 308,
310-312, 317, 319
- Soil washing (THRM/PHYS PSW-01), **I**:10-11;
IA:7, 13; **II**:135, 138, 141, 143, 145, 147-148,
153-155, 157, 159, 161, 164, 166, 168, 170-
171, 173, 175, 177, 179-180, 182, 185, 190,
192-194, 196-197, 199-200, 202, 204, 206,
208, 210, 219, 221-227, 229-230, 233-239,
241-243, 247-255, 257; **III**:208, 214, 216, 218,
220, 223, 226, 229, 232, 235, 279, 290
- Solid (waste form), **IB**:8, 11, 21, 24, 27; **II**:6, 8,
10, 12, 14-15, 17-25, 27-28, 30-31, 36, 38-39,
41-42, 44, 46-47, 49-51, 54, 60, 63-65, 67-68,
70-72, 74-75, 77, 79, 85, 121, 132, 190, 214,
219, 221-227, 230, 233-239, 241, 243, 246-
255, 257-259, 276; **III**:7, 9, 15, 25-26, 31, 33,
49, 52, 60, 62-65, 71-75, 79, 95, 122, 129,
146, 168, 170-171, 173, 176, 178, 181-182,
184, 195, 197-198, 201, 209, 268, 285, 291-
292, 306
- Solvent extraction (THRM/PHYS PSX-01), **I**:11;
II:6, 14, 18-19, 21, 23-24, 26, 28, 36, 39-40,
42, 44-45, 47-48, 50, 52-53, 60-61, 63, 65-66,
68, 70, 72, 74-75, 77-78, 80; **III**:41
- Statistical methods for spatially correlated data
(CHAR 75-IN), **IA**:4, 9; **II**:5, 50, 69; **III**:58
- Stoddard solvent, **IB**:5; **II**:7, 9, 11, 94-95, 137,
219-220
- Strontium (Sr-90), **I**:3; **IB**:4-14, 17-18; **II**:6-7, 9,
11-12, 14-15, 17, 19, 21-22, 24, 36, 45, 47, 60-
61, 63-64, 66, 80, 82, 93-100, 109, 113-114,
121-123, 130, 135-138, 140-145, 147-148, 163,
171-174, 190-191, 193-195, 197, 209, 211-212,
219-225, 233, 236-237, 247, 254, 256, 263-
266, 274; **III**:3, 5, 9, 11, 15, 17, 23, 25, 27,
29, 31, 33, 35, 37, 41, 43, 50, 52, 58, 60, 63,
65, 67, 69, 71, 77, 79, 85, 87, 91, 97, 101-102,
104, 110, 119, 122, 129, 136, 140, 146, 150,
153, 157, 159, 162, 167, 169, 180, 188, 190,
192, 206, 212, 214, 216, 218, 220, 223, 226,
229, 232, 235, 237, 243, 245, 247, 249, 263,
269, 271, 273, 279, 282, 284, 286, 288, 290,
294, 296, 298, 304
- Subsurface bioremediation (BICH-O-SSB), **IA**:5,
11; **II**:152, 184, 187-189, 213; **III**:259
- Subsurface complexation (CHAR 45-IN), **IA**:4, 9;
II:7, 9-10, 12, 14, 19, 21, 24, 26, 28-29, 37-
38, 40, 43, 45-46, 48, 50-52, 55, 61-62, 64, 66-
67, 69, 72-73, 75-76, 78-79, 81; **III**:29
- Sulfates, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220;
III:204, 241, 243, 280
- Supercritical fluid extraction--multidetector gas
chromatography (SFE-GC) (CHAR 115-IN),
IA:4, 9; **II**:32, 42, 56, 58; **III**:99-100
- Supercritical water oxidation (THRM/PHYS TO-02),
IA:7, 13; **II**:219-220, 231, 240, 244, 246, 257-
259; **III**:312

Surfactant wash (BICH-024), **IA**:6, 11; **II**:154-155, 186, 189; **III**:195, 208-209

Surfactant wash/dilute nitric acid washing (BICH-034), **IA**:6, 11; **II**:154-155, 186; **III**:208

T

Tap Magic, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Technetium, **II**:57; **III**:4, 6, 10, 12-13, 18-19, 21, 24, 26, 28, 30, 32, 34, 38-39, 42-43, 51, 53-54, 56, 58, 61, 64, 66, 68, 70, 80, 83, 85-86, 92, 96

Teleoperated excavation equipment (RETR-RE-001), **IA**:5, 11; **II**:93-100, 102-104, 109-117, 120-131; **III**:146

Tetryl, **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 259, 296, 304, 308, 311-312

Texal-40, **IB**:5; **II**:94-95, 137, 219

Toluene, **IB**:24, 27; **II**:53, 59, 117, 119, 182, 189, 240, 245, 271; **III**:3, 5, 7, 11, 25, 27, 29, 35, 41, 50, 67, 69, 73, 75, 85, 87, 91, 97, 102, 104, 119, 136, 140, 146, 204, 216, 223, 232, 255, 257, 259, 282, 284, 286, 292, 294, 296, 300, 302, 306, 308, 311-312

TRA-13, **III**:119, 129, 146

TRA-15, **IB**:7; **II**:14, 96, 138, 221, 265; **III**:3, 5, 9, 11, 15, 17, 23, 25, 27, 31, 35, 37, 41, 50, 52, 60, 63, 65, 67, 77, 79, 87, 91, 97, 101-102, 104, 110, 112, 119, 122, 129, 146, 150, 153, 159, 162, 188, 190, 212, 216, 223, 232, 237, 247, 279, 284, 290

TRA-36, **IB**:7; **II**:33, 105, 157; **III**:11, 31, 52, 67, 119, 122, 140, 150, 153, 157, 159, 171, 216, 223, 232

TRA-38, **III**:129

TRA-39, **IB**:8; **II**:33, 106, 159; **III**:11, 31, 52, 67, 119, 122, 129, 140, 150, 153, 157, 159, 171, 212, 216, 223, 232

Transuranic (TRU), **I**:12-13, 15; **IB**:24, 27; **II**:53, 59, 117, 119, 182, 240, 271; **III**:3, 5, 7, 11, 25, 27, 29, 35, 41, 50, 67, 69, 73, 75, 77, 85, 87, 91, 97, 102, 104, 110, 112, 119, 122, 129, 136, 140, 146, 204, 216, 223, 232, 257, 282, 284, 286, 294, 296, 300, 302, 304, 306, 308, 312

Tributyl phosphates, **IB**:11; **II**:40, 112, 166, 235; **III**:300, 302

Trichloroethane, **II**:85-86, 88, 132, 214-215, 258-259, 276; **III**:7, 9, 15, 31, 52, 60, 63, 65, 67, 73, 75, 79, 95, 119, 122, 136, 140, 146, 182, 184, 284, 298, 308, 312

Trichloroethylene (TCE), **IB**:6, 24, 27; **II**:53, 59, 94-95, 117, 119, 182, 189, 219-220, 240, 245, 271; **III**:3, 5, 7-8, 11, 13, 18, 21, 24-27, 29-30, 32, 35, 38-39, 41-43, 50, 53-54, 56, 58, 67-70, 73-76, 78, 81, 83, 85, 87, 91, 97, 99, 102, 104, 119, 122, 129, 136, 140, 146, 204, 216, 223, 232, 255, 257, 259, 282, 284, 286, 288, 292, 294, 296, 298, 300, 302, 306, 308, 311-312

Trinitrotoluene (TNT), **II**:83-84, 131, 213, 257; **III**:102, 104, 106, 108, 110, 253, 255, 259, 296, 304, 308, 311-312

Tritium, **IB**:9, 17-18; **II**:82, 212, 256; **III**:23, 85-86

TSF-03, **IB**:3; **II**:31, 104, 152, 228; **III**:9, 11, 15, 31, 33, 48, 52, 60, 63, 65, 67, 73, 75, 79, 95, 99, 122, 129, 146, 208, 214, 220, 229, 257, 284, 290, 298, 300, 302

TSF-06, **IB**:4; **II**:6, 93, 135, 219, 263; **III**:11, 29, 35, 41, 50, 52, 67, 69, 71, 77, 85, 87, 91, 97, 102, 104, 110, 112, 122, 129, 136, 140, 146, 150, 153, 159, 167, 214, 220, 229, 245, 269, 271, 273, 290

TSF-07, **IB**:6; **II**:37, 110, 164, 233, 269; **III**:3, 5, 11, 25, 27, 29, 35, 41, 50, 52, 67, 69, 71, 77, 85, 87, 91, 97, 112, 119, 122, 129, 136, 140, 146, 197, 218, 226, 235, 249, 267, 288, 290, 298

TSF-08, **IB**:6; **II**:56, 118, 184, 242; **III**:11, 15, 67, 129, 173, 267, 281, 298

TSF-38, **III**:9, 11, 15, 31, 33, 48, 52, 60, 63, 65, 67, 73, 75, 79, 95, 122, 129, 146, 162, 253, 255, 259, 282, 284, 298, 300, 302

U

Unexploded ordnance (UXO), **IB**:29; **II**:83-84, 131, 213, 257; **III**:147, 259, 296

Uranium, **I**:2, 1, 14; **IB**:6; **II**:3-4, 104, 135, 138, 140-141, 143, 145, 147, 149-150, 153-154, 156-157, 159, 161, 164, 167-170, 172-173, 175, 177, 179-180, 182, 185, 190, 192-194, 196, 198-199, 201, 203-204, 206, 208, 210, 222, 224-225, 230, 242, 249; **III**:2, 4, 6, 10, 12-13, 18-19, 21, 24, 26, 28, 30, 32, 34, 38-39, 42-43, 48, 51, 53-54, 56, 58, 61, 64, 66, 68, 70, 80, 89, 92, 96, 98, 220, 223, 226, 238, 240-244, 252, 268, 279, 298

Uranium-234, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Uranium-235, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220; **III**:87-89, 93

Uranium-236, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220

Uranium
220;

V

Vacuum-
meth
19, 2
48, 5
75, 7

Vapor va
IA:7
245;

Visual di
IN),

W

Waste C
IA:4

Water ba
13; **I**

Water ba
IA:7

Wavelen
WD;
III:4

Wet air c
II:2

WRRTF
III:
229,

X

X-ray di
12,
65; **I**

X-ray fl
II:1

Uranium-238, **IB**:5; **II**:7, 9, 11, 94-95, 137, 219-220; **III**:87-88, 93

V

Vacuum-assisted, reverse-flow solvent extraction methods (CHAR 62-IN), **IA**:4, 9; **II**:6, 14, 18-19, 21, 23-24, 26, 28, 36, 39-40, 42, 44-45, 47-48, 50, 52-53, 60-61, 63, 65-66, 68, 70, 72, 74-75, 77-78, 80; **III**:41

Vapor vacuum extraction (THRM/PHYS PVV-01), **IA**:7, 13; **IB**:24, 27-28; **II**:120, 231, 241-242, 245; **III**:292

Visual display of statistical information (CHAR 73-IN), **IA**:4, 9; **II**:4-5; **III**:56

W

Waste Curie Monitoring (semi-lab) (CHAR 109-IN), **IA**:4, 9; **II**:3-4; **III**:93

Water balance caps (CAPS CB-02), **I**:14-15; **IA**:7, 13; **II**:263-277; **III**:317, 319

Water based reactive plasma (THRM/PHYS PF-01), **IA**:7, 13; **II**:231, 244; **III**:276

Wavelength-dispersive x-ray spectroscopy (WDS, WDX) (CHAR 66-IN), **IA**:4, 9; **II**:30-31, 41; **III**:48

Wet air oxidation (THRM/PHYS TO-01), **IA**:7, 13; **II**:245; **III**:311

WRRTF-01, **IB**:4; **II**:32, 104, 154, 229, 267; **III**:11, 31, 52, 67, 122, 129, 208, 214, 220, 229, 257, 284, 290, 298, 300, 302

X

X-ray diffraction (CHAR 31-IN), **IA**:4, 9; **II**:8, 10, 12, 14-15, 18, 20-21, 23, 25, 38, 41, 51, 54, 65; **III**:25

X-ray fluorescence (CHAR 6-IN, 98-IN), **IA**:4, 9; **II**:16, 30, 32, 66, 83-84, 86-87, 89; **III**:9, 79

END

DATE

FILMED

4/25/94