1 of 1

HAZARDOUS WASTE TREATMENT
AND
ENVIRONMENTAL REMEDIATION
RESEARCH

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1. INTRODUCTION

Los Alamos National Laboratory (LANL) is currently evaluating hazardous waste treatment and environmental remediation technologies in existence and under development to determine applicability to remediation needs of the DOE facilities under the Albuquerque Operations Office and to determine areas of research need. To assist LANL in this effort, Science Applications International Corporation (SAIC) conducted an assessment of technologies and monitoring methods that have been demonstrated or are under development. The focus of this assessment is to:

1. Identify existing technologies for hazardous waste treatment and environmental remediation of old waste sites.
2. Identify technologies under development and the status of the technology.
3. Assess new technologies that need development to provide adequate hazardous waste treatment and remedial action technologies for DOD and DOE sites.
4. Identify hazardous waste and remediation problems for environmental research and development.

There are currently numerous research and development activities underway nationwide relating to environmental contaminants and the remediation of waste sites. To perform this effort, SAIC evaluated current technologies and monitoring methods development programs in EPA, DOD, and DOE, as these are the primary agencies through which developmental methods are being demonstrated. This report presents this evaluation and provides recommendations as to pertinent research needs or activities to address waste site contamination problems. The review and assessment have been conducted at a programmatic level; site-specific and contaminant-specific evaluations are being performed by LANL staff as a separate, related activity.

This report is organized into four sections. Section 2 presents an assessment of the developmental status of various remediation and hazardous waste treatment technologies. Section 3 presents an evaluation of the current status of measurement and monitoring techniques for site characterization to support remediation. Section 4 summarizes current areas of ongoing research in both remediation/treatment technologies and monitoring/measurement techniques. Section 5 presents technology development needs and identifies areas of hazardous waste and remediation problems for environmental research and development. Section 5 also presents overall program recommendations.

2. HAZARDOUS WASTE TREATMENT AND ENVIRONMENTAL REMEDIATION TECHNOLOGIES

There are a wide range of technologies available and under development that pertain to hazardous waste treatment and environmental remediation. For the purposes of this report, hazardous waste treatment technologies may be considered a subset of environmental remediation technologies as the remediation technologies cover a broader range of actions. Remediation technologies may be oriented toward prevention of human exposure while others may specifically address the removal or detoxification of contaminated materials. Once a material such as soil or groundwater has been removed from the environment, the options available to treat the material are often the same as those available to treat hazardous wastes.

Much of the current remediation and hazardous waste treatment technology demonstration activities are being conducted through the Environmental Protection Agency (EPA) under the Superfund Innovative Technology Evaluation (SITE) Program, by the U.S. Air Force under the Installation Restoration Program, by the U.S. Army Corps of Engineers in support of Superfund efforts, by the U.S. Army to support their cleanup efforts and by the Department of Energy through its various facilities and laboratories nationwide. A search of these current activities enabled the identification of 30 broad ranges of technologies for environmental remediation and hazardous waste treatment:

- Administrative controls
- Alternate water supplies
- Capping
- Covers
- Disposal
- Diversion and collection systems
- Dust control
- Gas collection
- Gaseous treatment
- Grading
- Groundwater pumping
- Horizontal barriers
- In-situ treatment

- Liquid treatment--biological
- Liquid treatment--chemical
- Liquid treatment--physical
- Revegetation
- Sediment removal
- Sediment turbidity controls
- Sewer line removal/replacement
- Soil excavation
- Solidification/encapsulation/fixation
- Solids separation
- Solids treatment
- Structural cleaning
- Subsurface liquid collection
- Temporary storage
- Thermal treatment
- Vertical barriers
- Waste removal.

The above categories of technologies address all potential technology applications for control of contaminants and exposure. The applications identified are defined below:

- Access control - methods to prevent unknowing access to contaminated areas thereby reducing potential for exposure of humans, agricultural animals, and wildlife.
- Water supply control - methods to provide alternate water supply to replace a contaminated water supply (in lieu of treatment) thereby reducing/eliminating exposure of humans, agricultural crops/animals, or wildlife.
- Gas/vapor transport control - methods to prevent/reduce the movement of gases/vapors from one media to another (e.g., from soil to air) or to remove gases/vapors from the subsurface for treatment or to prevent additional site problems such as the potential for explosions.
- Air pollution controls - methods to prevent contaminants from entering the atmosphere, primarily through prevention of wind entrainment of contaminated particulates.
- Leachate control - methods to prevent/reduce the formation of leachate or to prevent/reduce further migration of leachate already generated.

- Groundwater pollution control - methods to prevent/reduce the further spread of contaminants present in the groundwater and to extract contaminated groundwater for treatment.
- Surface water pollution control - methods to prevent/reduce contact of surface waters (e.g., rivers, creeks, lakes) with contaminated sediments.
- Waste control - methods to isolate wastes in place or to prevent further migration of waste constituents into surrounding environmental media.
- Surface water control - methods to prevent contact of precipitation and precipitation runoff with contaminated materials or to prevent ponding of precipitation in contaminated areas thereby contributing to leachate generation and contaminant transport.
- Final disposition - methods for permanent disposal of waste or contaminated media residuals following excavation/treatment.
- Gas/vapor treatment - methods to treat gases or vapors removed from the subsurface or generated in the course of waste or contaminated media treatment.
- Erosion control - methods to control land surface features to prevent erosion by surface water or precipitation runoff.
- Groundwater control - methods to control the movement of groundwater in the local area to prevent contact with contaminated groundwater or other media; this includes methods for reinjection of treated groundwater.
- Contaminated soils control - methods to remove contaminated soils or to treat contaminants present in soils without excavation.
- Structure contamination control - methods to decontaminate buildings or sewer lines without having to dismantle the structures.
- Liquid treatment - methods to treat aqueous and nonaqueous liquids such as wastes or contaminated groundwater or surface water.
- Solids treatment - methods to separate solids from a "liquid" and methods to treat contaminated solids such as wastes, contaminated soils, or sediments.
- Drinking water treatment - methods to treat an existing drinking water supply without replacement of the supply itself.
- Land reclamation - methods to revegetate a remediated area.
- Temporary holding - methods for temporarily storing wastes or contaminated materials prior to treatment or disposal.

Table 2-1 provides a listing of the existing technologies for hazardous waste treatment and environmental remediation of old waste sites based on the research conducted in support of this report. The table identifies the technologies by the 30 categories identified above and also identifies the individual technology variations within a particular category. Based on the 30 technology categories, more than 220 technology variations have been identified. The application(s) suitable for each technology category are also identified. These applications are based on the entire technology category rather than specific technology applications that may appear directly next to the variation in the table. References for the technology and development status information are identified by number in Table 2-1 and are provided in a complete listing at the end of this section.

Table 2-1 identifies the state of development of each technology. Many of the technologies identified are in place or proven for a particular material or waste constituent as denoted by "demonstrated." It is possible that some of the technologies identified as "demonstrated" have not been demonstrated for a full range of constituents (i.e., organic chemicals, inorganic chemicals, and radionuclides). For the purposes of this report, the technologies were reviewed on a programmatic basis. Contaminant-specific evaluations of individual technologies would be performed as part of engineering feasibility studies associated with remediation planning and implementation. Thus, bench-scale or pilot-scale testing of a particular treatment technology application may be required even for demonstrated technologies to ensure that the range of constituents or the specific conditions present at the site could be adequately handled by the technology.

Many of the technologies identified in Table 2-1 are denoted as developmental. This indicates that the particular technology is either (1) not yet proven or has undergone bench-, pilot-, or field demonstrations, but not full technology application, or (2) must undergo bench/pilot testing prior to each application because the treatment chemical selection or contaminant sensitivity is site-specific. For this reason, some technologies such as bioreclamation may appear as developmental when in fact the technology has undergone numerous applications across the United States.

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
ADMINISTRATIVE CONTROLS	Access Control	Fencing	Demonstrated	40 CFR 302
		Warning Signs	Demonstrated	40 CFR 302
		Security Guards	Demonstrated	General Knowledge
		Federal Land Control	Demonstrated	General Knowledge
ALTERNATE WATER SUPPLIES	Water Supply Control	Bottled Water	Demonstrated	5
		Cisterns/tanks	Demonstrated	12
		Relocate Production Well	Demonstrated	5
		Tie into Municipal System	Demonstrated	5
		Relocate Surface Water Intake	Demonstrated	5
CAPPING	Gas/Vapor Transport Control Air Pollution Control Leachate Control Groundwater Pollution Control Surface Water Pollution Control	Clay	Demonstrated	2, 5, 12
		Asphalt	Demonstrated	5, 12
		Synthetic Membrane	Demonstrated	2, 5, 12
		Fly Ash	Demonstrated	5, 12
		Soil Fly Ash	Demonstrated	5, 12
		Multilayered System	Demonstrated	2, 5, 12
		Concrete	Demonstrated	5, 12
		Chemical Sealant/Stabilizer	Demonstrated	5, 12
COVERS	Air Pollution Control Surface Water Control Waste Control	Single Layer Cap	Demonstrated	5
		Floating Covers	Demonstrated	5, 9
DISPOSAL	Final Disposition	Discharge to POTW	Demonstrated	12
		Landfill	Demonstrated	5, 12
		Surface Impoundment	Demonstrated	12
		Land Application/Spreading	Demonstrated	2, 5, 12
		Waste Pile	Demonstrated	12
		Deep Well Injection	Demonstrated	12

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
DISPOSAL (Continued)		Deep Geologic Repository	Developmental	General Knowledge
		Ocean Disposal	Demonstrated	2
		Underground Mine	Developmental	2
DIVERSION AND COLLECTION SYSTEMS	Surface Water Control	Dike	Demonstrated	5
		Berm	Demonstrated	5
		Ditch	Demonstrated	5
		Trench	Demonstrated	5
		Diversions	Demonstrated	5
		Terrace	Demonstrated	5
		Bench	Demonstrated	5
		Downpipe	Demonstrated	5
		Chute	Demonstrated	5
		Culvert	Demonstrated	5
		Seepage Basin	Demonstrated	5
		Sedimentation Basin	Demonstrated	5
		Levee	Demonstrated	12
		Floodwall	Demonstrated	12
DUST CONTROL	Air Pollution Control	Polymers	Demonstrated	5, 12
		Water Spray	Demonstrated	5, 12
		Chemical Solutions	Demonstrated	5, 12
		Wind Fences/Screens	Demonstrated	5, 12
GAS COLLECTION	Gas/Vapor Transport Control	Passive Pipe Vents	Demonstrated	5
		Passive Trench Vents	Demonstrated	5
		Active Extraction Systems	Demonstrated	3, 5, 6, 11
		Contour Furrowing	Demonstrated	5

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
GASEOUS TREATMENT	Gas/Vapor Treatment	Activated Carbon	Demonstrated	5
		Flares	Demonstrated	5
		Afterburners	Demonstrated	12
		HEPA Filters	Demonstrated	General Knowledge
		Scrubbers	Demonstrated	General Knowledge
GRADING	Surface Water Control Erosion Control	Scarification Tracking	Demonstrated	5
			Demonstrated	5
GROUNDWATER PUMPING	Groundwater Control Groundwater Pollution Control Leachate Control	Extraction Wells Injection Wells Wellpoint System	Demonstrated	5
			Demonstrated	5
			Demonstrated	5
HORIZONTAL BARRIERS	Waste Control Contaminated Soils Control	Block Displacement Grout Injection	Developmental	5
			Developmental	5
IN-SITU TREATMENT	Contaminated Soils Control Waste Control Groundwater Pollution Control Gas/Vapor Transport Control	Hydrolysis Oxidation Reduction Soil Aeration Soil Flushing Neutralization Polymerization Bioreclamation Permeable Treatment Beds Chemical Dechlorination Vitrification Precipitation Stabilization/Solidification Chelation	Developmental	5, 12
			Developmental	5
			Developmental	5
			Developmental	12
			Developmental	3, 5, 11
			Developmental	5
			Developmental	5
			Developmental	3, 5, 6, 11
			Developmental	5
			Developmental	12
			Developmental	2, 3, 5, 11
			Developmental	5
			Developmental	2, 3, 5, 7, 11
			Developmental	5
			Developmental	

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
IN-SITU TREATMENT (Continued)		Enzymatic Degradation	Developmental	5
		Heating	Developmental	5
		Ground Freezing	Developmental	5, 12
		Electro Acoustic	New Technology	11
LIQUID TREATMENT--BIOLOGICAL	Liquid Treatment Solids Treatment	Activated Sludge	Demonstrated	5, 12
		Trickling Filters	Demonstrated	5, 12
		Aerated Lagoon	Demonstrated	12
		Waste Stabilization Ponds	Demonstrated	12
		Rotating Biological Discs	Demonstrated	5
		Bioreactors	Developmental	6, 11
LIQUID TREATMENT--CHEMICAL	Liquid Treatment Drinking Water Treatment	Neutralization	Demonstrated	5
		Precipitation	Demonstrated	5
		Oxidation	Demonstrated	3, 5
		Hydrolysis	Demonstrated	12
		Reduction	Demonstrated	3, 5
		Chemical Dechlorination	Developmental	12
		Photochemical/Ozonation	Developmental	5, 6, 11
LIQUID TREATMENT--PHYSICAL	Liquid Treatment Drinking Water Treatment	Flow Equalization	Demonstrated	12
		Flocculation	Demonstrated	5
		Sedimentation	Demonstrated	5
		Activated Carbon	Demonstrated	5
		Ion Exchange	Demonstrated	5, 11
		Reverse Osmosis	Demonstrated	5
		Liquid/Liquid Extraction	Developmental	11, 12
		Evaporation	Demonstrated	General Knowledge
		Oil/Water (Gravity) Separation	Demonstrated	5, 12
		Steam Distillation	Demonstrated	12
		Air Stripping	Demonstrated	5, 6

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
LIQUID TREATMENT--PHYSICAL (Continued)		Trees-hardwood	Demonstrated	5, 12
		Steam Stripping	Demonstrated	12
		Filtration	Demonstrated	5
		Dissolved Air Flotation	Demonstrated	12
		Sorbents	Demonstrated	5, 11
		Sorptive Resins	Demonstrated	5, 11
		Stabilization	See Solidification	
		Ultrafiltration	Demonstrated	11
		Freezing	Developmental	11
		Distillation	Demonstrated	5
REVEGETATION	Erosion Control Land Reclamation	Grasses	Demonstrated	5, 12
		Legumes	Demonstrated	5, 12
		Shrubs	Demonstrated	5, 12
		Trees-conifers	Demonstrated	5, 12
SEDIMENT REMOVAL	Surface Water Pollution Control	Mechanical Dredging	Demonstrated	5
		o Clamshell	Demonstrated	5
		o Dragline	Demonstrated	5
		o Backhoe	Demonstrated	5
		o Bucket Ladder	Demonstrated	5
		Hydraulic Dredging	Demonstrated	5
		o Plain Suction	Demonstrated	5
		o Dredpan	Demonstrated	5
		o Cutterhead	Demonstrated	5, 6
		o Hopper	Demonstrated	5
		o Portable	Demonstrated	5
		o Handheld	Demonstrated	5
		Pneumatic Dredging	Demonstrated	5
		o Airlift	Demonstrated	5
		o Pneuma	Developmental	5
		o Dozer	Developmental	5

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
SEDIMENT TURBIDITY CONTROLS	Surface Water Pollution Control	Curtain Barrier	Demonstrated	5
		Cofferdam	Demonstrated	5
		Pneumatic Barrier	Demonstrated	12
SEWER LINE REMOVAL/REPLACEMENT	Sewer Contamination Control	None	Demonstrated	5
SOIL EXCAVATION	Contaminated Soils Control	Backhoe	Demonstrated	5
		Cranes and Attachments	Demonstrated	5
		Front End Loaders	Demonstrated	5
		Scrapers	Demonstrated	5
SOLIDIFICATION/ENCAPS/FIXATION	Solids Treatment Liquid Treatment Waste Control	Cement-Based	Demonstrated	2, 3, 5, 7
		Lime-Based	Demonstrated	12
		Thermoplastic	Developmental	2, 3, 5, 12
		Organic Polymer	Developmental	3, 7
		Self-Cementing Techniques	Developmental	3, 5, 7, 12
		Surface Microencapsulation	Developmental	5, 7
SOLIDIFICATION/ENCAPS/FIXATION (continued)		Vitrification	Developmental	5, 7, 12
		Sorbents	Developmental	5, 12
		Silicate-Based	Developmental	3, 5
SOLIDS SEPARATION	Solids Treatment Liquid Treatment	Sieve	Demonstrated	5
		Screen	Demonstrated	2, 5
		Spiral Classifier	Demonstrated	5
		Hydraulic Classifier	Demonstrated	5
		Scalper	Demonstrated	12
		Centrifugation	Demonstrated	5
		Gravity Thickening/Conc.	Demonstrated	2, 5

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
SOLIDS SEPARATION (Continued)		Flocculation/Flotation	Demonstrated	2, 5
		Sedimentation	Demonstrated	5
		Filter Press	Demonstrated	5
		Filtration	Demonstrated	5
		Drying or Dewatering Bed	Demonstrated	12
		Vacuum Assisted Drying Bed	Demonstrated	12
		Gravity Settling	Demonstrated	5, 6
		Cyclone	Demonstrated	5
		Hydrocyclone	Demonstrated	5
		Clarifier	Demonstrated	5
SOLIDS TREATMENT	Solids Treatment	Neutralization	Demonstrated	12
		Chemical/Solvent Extraction	Developmental	2, 3, 11, 12
		Oxidation	Developmental	12
		Reduction	Developmental	12
		Composting	Demonstrated	3, 6, 12
		Vitrification	Developmental	3
		Bioreactor (slurry)	Developmental	3
		Biodegradation	Developmental	1
		Sorbents	Developmental	1
		Soil Washing	Developmental	2, 3, 11
		Chemical Dechlorination	Developmental	3, 6
		Low Temp Thermal Stripping	Developmental	3, 6
		Electro Acoustic	Developmental	6
STRUCTURAL CLEANING	Structure Contamination Control	Mechanical Scouring	Demonstrated	5
		Hydraulic Scouring	Demonstrated	5
		Bucket Dredging	Demonstrated	5
		Chemical Cleaning	Developmental	5
		Heating	Developmental	6

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
SUBSURFACE LIQUID COLLECTION	Leachate Control Groundwater Pollution Control Waste Control	French Drains	Demonstrated	12
		Conventional Pipe Drains	Demonstrated	12
		Dual Media Pipe Drains	Demonstrated	12
		Tile Drains	Demonstrated	1
TEMPORARY STORAGE	Temporary Holding	Containers	Demonstrated	12
		Tanks	Demonstrated	12
		Surface Impoundment	Demonstrated	12
		Waste Pile	Demonstrated	12
THERMAL TREATMENT	Solids Treatment Liquids Treatment	Rotary Kiln	Demonstrated	3, 4, 5, 6
		Fluidized Bed	Developmental	3, 4, 5
		Multiple Hearth	Demonstrated	4, 5
		Liquid Injection	Demonstrated	4, 5
		Molten Salt	Developmental	4, 5
		High Temperature Fluid Wall	Developmental	5
		Plasma Arc	Developmental	4, 5, 11
		Pyrolysis/Starved Air Combustion	Developmental	3, 4, 5
		Wet Air Oxidation Combustion	Demonstrated	3, 4, 5
		Infrared Incineration	Developmental	3, 4, 11
		Auger Combustor	Demonstrated	4
		Calcination	Demonstrated	4
		Catalytic Incineration	Developmental	4
		Circulating Bed	Developmental	3, 4, 5, 11
		Cyclonic Incinerator	Developmental	4
		Electric Reactor (Fluid Wall)	Developmental	4, 5
		Fume Incinerator	Demonstrated	4
		Hearth	Demonstrated	4
		Industrial Kiln	Demonstrated	4
		Industrial Boiler	Demonstrated	4
		Microwave Plasma	Developmental	4
		Molten Glass	Developmental	4

TABLE 2-1. SUMMARY OF ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES
(continued)

TECHNOLOGY	APPLICATION	VARIATION	STATE OF DEVELOPMENT	REFERENCE
THERMAL TREATMENT (Continued)		Multiple Chamber	Demonstrated	4
		Supercritical Liquid Oxidation	Developmental	3, 4, 5
		Thermal Desorption	Developmental	11
		Open Burning/Detonation	Demonstrated	General Knowledge
VERTICAL BARRIERS				
	Groundwater Pollution Control	Soil-Bentonite Slurry Wall	Demonstrated	5, 12
	Groundwater Control	Cement-Bentonite Slurry Wall	Demonstrated	5, 12
	Leachate Control	Synthetic Liners	Demonstrated	5
	Waste Control	Vibrating Beam Asphalt Wall	Demonstrated	12
	Gas/Vapor Transport Control	Grout Curtain	Developmental	5, 10, 12
		Steel Sheet Piling Wall	Demonstrated	5, 12
		Envirowall Cut-Off	Developmental	12
WASTE REMOVAL				
	Waste Control	Backhoe	Demonstrated	5
		Cranes and Attachments	Demonstrated	5
		Front End Loaders	Demonstrated	5
		Scrapers	Demonstrated	5
		Industrial Vacuums	Demonstrated	5
	Pumps	Drum Grapplers/Forklifts	Demonstrated	5

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3. MONITORING AND MEASUREMENT METHODS

A number of monitoring and measurement methods are currently in use for site characterization to understand the geology, vadose zone, and groundwater systems at waste sites. These methods are employed to obtain the necessary data to understand the physical characteristics of a given site, potential contaminant transport pathways, subsurface features affecting contaminant transport, and contaminant distribution in the subsurface as well as developing and validating site-specific mathematical models of contaminant fate and transport.

Examination of the current methodologies for field data collection identified five broad areas of activities pertaining to monitoring and measurement methods. These areas are: field methods, vadose zone instrumentation, monitoring techniques for assessing fluid characteristics, in-situ geomechanical testing techniques, and characterization techniques. Table 3-1 presents these five areas of monitoring and measurement methods, identifies the specific methods in each area, identifies the variations of the specific methods, and identifies the pertinent application of the specific methods. References are included in the table and may be found at the end of this section.

The applications identified for the monitoring and measurement methods in Table 3-1 include:

- In-situ or field measurement of chemical and radiological parameters
- In-situ characterization of soil gases or groundwater
- Identification of subsurface geologic features
- Characterization of subsurface physical properties such as fractures, porosity, etc.
- Obtaining samples (soil, bedrock, groundwater) for subsequent physical characteristics testing (soil, bedrock) or chemical analysis (soil, bedrock, groundwater)
- Defining hydrologic properties of the vadose zone and saturated zone
- Defining aquifer characteristics
- Determining transport pathways.

A total of 38 methods have been identified in the five measurement areas. This includes over 120 method variations.

TABLE 3-1. SUMMARY OF CURRENT SUBSURFACE MONITORING AND MEASUREMENT METHODS

METHOD	VARIATION	APPLICATION	REFERENCES
FIELD METHODS			
Portable Field Instrumentation	I-Ray Fluorescence	In-Situ Trace element detection	14
	MMU	Field instrument to detect hydrocarbons in the working zone	5
	DWA	Field instrument to detect hydrocarbons in the working zone	5
Soil Gas	Curie-Point Wire Accumulator Device	In-situ characterization of soil gas emission from source	7
	Ground Probes	In-situ characterization of soil gas emission from source	7
	Passive Ground Probes	In-situ characterization of soil gas emission from source	7
	Borehole (Well)	In-situ characterization of soil gas emission from source	7
Surface Geophysics	Electromagnetic	Characterizing subsurface features and geology	1, 3, 5
	Magnetometer	Characterizing subsurface features and geology	1, 3, 5
	VLF	Characterizing subsurface features and geology	1, 3, 5
	Seismic Refraction	Characterizing subsurface features and geology	1, 3, 5
	Resistivity/Conductivity	Characterizing subsurface features and geology	1, 3, 5
Borehole Geophysics:	Natural Gamma	In-situ characterization of subsurface	1, 3, 4, 5
	Gamma Spectrometry	In-situ characterization of subsurface	1, 3, 4, 5
	Gamma-Gamma Density	In-situ characterization of subsurface	1, 3, 4, 5
	Pulsed Neutron	In-situ characterization of subsurface	1, 3, 4, 5
Radiative Logging Techniques	Single-Point Resistance	Characterizing subsurface properties and fracture	1, 3, 4, 5
	Normal Resistivity	Characterizing subsurface properties and fracture	1, 3, 4, 5
	Focused Resistivity	Characterizing subsurface properties and fracture	1, 3, 4, 5
	Spontaneous Potential Induction	Characterizing subsurface properties and fracture	1, 3, 4, 5
	Acoustic	Characterizing subsurface properties and fracture	1, 3, 4, 5
Electric Logging Techniques	Seismic-Reflection	Characterizing subsurface properties and fracture	1, 3, 4, 5
	Seismic-Refraction	Characterizing subsurface properties and fracture	1, 3, 4, 5
Elastic Wave Propagation	Tube Wave	Characterizing subsurface properties and fracture	1, 3, 4, 5
	Caliper	In-situ characterization of borehole's physical diameter	1, 3, 4, 5
Logging Techniques	Temperature	Characterization of groundwater	1, 3, 4, 5

TABLE 3-1. SUMMARY OF CURRENT SUBSURFACE MONITORING AND MEASUREMENT METHODS
(continued)

METHOD	VARIATION	APPLICATION	REFERENCES
Television Logging	Acoustic Optical	Viewing borehole	1, 3, 4, 5 1, 3, 4, 5
Gravity Logging			
Radar Logging			
Flow Velocity Logging	Heat Pulse Mechanical Spinner	Determining groundwater velocity	4, 13
Innovative Techniques	Ray Optic Seismography Diffusion Seismography Cross-Hole Techniques	Determining three dimensional porosity and lithology Determining three dimensional porosity and lithology Determining three dimensional porosity and lithology	2, 4, 17 2, 4, 17 2, 4, 17
Vadose Zone Instrumentation:			
Indirect Methods	4 Probe electric Method Electrical Conductivity Probe Salinity Sensors Electric Resistance Blocks		8, 12, 13 8, 12, 13 8, 12, 13 8, 12, 13
Direct Methods	Suction lysimeters vacuum pressure lysimeter High-pressure Vacuum pressure lysimeter Tensiometer Psychrometers Neutron moisture Membrane Filter Sampler	Measure soil water content or soil-water pressure Obtain liquid sample Obtain liquid sample Obtain liquid sample Measure water moisture Soil water pressure in dry conditions Soil-geophysics method to determine water content Soil water collection	8, 12, 13 8, 12, 13 8, 12, 13 8, 12, 13 8, 12, 13 8, 12, 13 8, 12, 13
MONITORING TECHNIQUES FOR ASSESSING FLUID CHARACTERISTICS			
Piezometers/Monitoring Wells	Single Piezometers/wells Multiple Piezometers/wells Multiple-Port Piezometers/wells Bottom-Hole Shut In Pressure Tests	Characterizing hydrologic properties Characterizing hydrologic properties Characterizing hydrologic properties Characterizing hydrologic properties	1, 3, 5, 6, 12 1, 3, 5, 6, 12 1, 3, 5, 6, 12 1, 3, 5, 6, 12
Fiber Optics Chemical Sensors	Reservoir Sensors Tip Coated Sensors Multilayer Solid State Infrared spectroscopy (IS)	Aluminum, Aniline, Bile Acids, Biological Agents, Carbon Dioxide, Chemical Agents, Copper, Cyanide, Explosives, Detergents, Gasoline Components, Hydrogen Sulfide, Jet Fuel Kerosene, Nitrates, Oxygen, pH, Phenol, Phosphate, Plutonium,	9, 10 9, 10 9, 10 9, 10

TABLE 3-1. SUMMARY OF CURRENT SUBSURFACE MONITORING AND MEASUREMENT METHODS
(continued)

METHOD	VARIATION	APPLICATION	REFERENCES
	Fluorescence spectroscopy	Redox Potential, Organic Chlorides, Sulfate, Tracers, Uranium	9, 10
	Surface enhanced Raman Spectroscopy		9, 10
	Optrodes	Nitrate	9, 10
	Stripping voltametry	Chromium	9, 10
	Mass sensitive Devices	Carbon Tetrachloride	9, 10
	Spark excitation-optical emission spectroscopy	Cyanide	9, 10
	Photoacoustic spectroscopy	Fluoride	9, 10
		TCE	9, 10
		TCA, PCE, DCA, DCE	9, 10
		HEX	9, 10
		Chloroform	9, 10
		Uranium	9, 10
		Hydrocarbons	9, 10
		TNT	9, 10
SAMPLING TECHNIQUES			
Groundwater Sampling	Teflon bailer	Sampling groundwater	1, 4, 5, 7, 12
	Kemmer sampler	Sampling groundwater	1, 4, 5, 7, 12
	Syringe sampler	Sampling groundwater	1, 4, 5, 7, 12
	Bladder pumps	Sampling groundwater	1, 4, 5, 7, 12
	Suction-Lift Pumps	Sampling groundwater	1, 4, 5, 7, 12
	Submersible Pumps	Sampling groundwater	1, 4, 5, 7, 12
	Nitrogen-Powered, Continuous -Delivery, Class-Teflon Sampler	Sampling groundwater	1, 4, 5, 7, 12
Geological Sampling	Split-spoon Samplers	Sampling soils and subsurface lithology	1, 4, 5, 7, 12
	Thin-walled tube samplers	Sampling soils and subsurface lithology	1, 4, 5, 7, 12
	Cutting or Wash Samplers	Sampling soils and subsurface lithology	1, 4, 5, 7, 12
Drilling Techniques	Hand Augers	Used to obtain subsurface samples and provide borehole	1, 4, 5, 7, 12
	Powered Augers	Used to complete well installation	1, 4, 5, 7, 12
	Hollow-stem Augers	Used to obtain subsurface samples and provide borehole	1, 4, 5, 7, 12
	Solid-stem Augers	Used to complete well installation	1, 4, 5, 7, 12
	Bucket and Bit Augers	Used to obtain subsurface sample and provide borehole	1, 4, 5, 7, 12
	Cable Tool	Used to complete well installation	1, 4, 5, 7, 12
	Red/water/foam Rotary Drilling	Used to obtain subsurface samples and provide borehole	1, 4, 5, 7, 12
	Air Rotary Method	Used to complete well installation	1, 4, 5, 7, 12
	Reverse Air/Water/foam Rotary Method	Used to obtain subsurface samples and provide borehole	1, 4, 5, 7, 12
	Burl Tube Drilling Method	Used to complete well installation	1, 4, 5, 7, 12
Water Level Instruments	Float	Measure static water level of the groundwater system	1, 4, 5, 7, 12
	Transducer	Measure static water level of the groundwater system	1, 4, 5, 7, 12
	Acoustic	Measure static water level of the groundwater system	1, 4, 5, 7, 12

TABLE 3-1. SUMMARY OF CURRENT SUBSURFACE MONITORING AND MEASUREMENT METHODS
(continued)

METHOD	VARIATION	APPLICATION	REFERENCES
Water Temperature	Thermistor Thermocouple Resistance Temperature Detector	Determine groundwater systems temperatures Determine groundwater systems temperatures Determine groundwater systems temperatures	1, 4, 5, 7, 12 1, 4, 5, 7, 12 1, 4, 5, 7, 12
IN-SITU GEOMECHANICAL TESTING TECHNIQUES			
Direct Deformational Methods	Borehole Jacks Dilatometers Penetrometers	Determine subsurface deformation capacity Determine subsurface deformation capacity Determine subsurface deformation capacity	3, 4, 6 3, 4, 6 3, 4, 6
Laboratory Methods:			
Stability of geological matrix openings	Brazilian tensile test Direct tension test Point-load test Uniaxial compression test Triaxial compression test Direct shear test (fractures) Bulk density measurements	Determine subsurface deformation capacity Determine subsurface deformation capacity Determine subsurface deformation capacity Determine subsurface deformation capacity Determine subsurface deformation capacity Determine subsurface deformation capacity Determine subsurface deformation capacity	3, 4, 6 3, 4, 6 3, 4, 6 3, 4, 6 3, 4, 6 3, 4, 6 3, 4, 6
Thermochemical Properties	Thermal expansion Thermal conductivity Specific heat	Determine thermochemical properties Determine thermochemical properties Determine thermochemical properties	3, 4, 6 3, 4, 6 3, 4, 6
Hydrochemical Properties	Permeability Porosity	Determine hydrological properties Determine hydrological properties	3, 4, 6 3, 4, 6
CHARACTERIZATION TECHNIQUES			
Constant-Rate Fluid Injection Tests	Small and large piezometers used with packer system	Determine aquifer characteristics	1, 3, 4, 5
Slug Tests	Small and large piezometers used with packer system	Determine aquifer characteristics	1, 3, 4, 5
Pumping and Recovery Tests	Small and large piezometers used with packer system	Determine aquifer characteristics	1, 3, 4, 5
Pressure-Pulse Tests	Small and large piezometers used with packer system	Determine aquifer characteristics	1, 3, 4, 5
Cross-Hole Interference Tests	Small and large piezometers used with packer system	Determine subsurface's three dimensional lithology and percolates	2, 4, 17

TABLE 3-1. SUMMARY OF CURRENT SUBSURFACE MONITORING AND MEASUREMENT METHODS
(continued)

METHOD	VARIATION	APPLICATION	REFERENCES
Tracer Technologies	Small and large piezometers used with packer system	Determine dispersivity values and direction of groundwater flow	2, 4, 17
Particles	Spores Bacteria Viruses	Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow	11 11 11
Ions	Chloride Bromide	Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow	11 11
Dyes	Rhodamine WT Fluorescein	Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow	11 11
Radioactive Tracers	Tritium Iodine 131 EDTA 51Cr Bromine Isotope 82	Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow	11 11 11 11
Other Tracers	Fluorocarbons Organic anions	Determine dispersivity values and direction of groundwater flow Determine dispersivity values and direction of groundwater flow	11 11

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4. CURRENT AREAS OF RESEARCH AND DEVELOPMENT

Research and development activities supporting waste site remediation and hazardous waste treatment are underway in numerous organizations across the country ranging from federally-sponsored studies to independent industrial research to support new product development. The primary focal points of research or demonstration at this time are the EPA, DOD, and DOE through their ongoing programs to address the cleanup of a wide range of contaminated media and facilities. The following sections summarize information obtained to date regarding current areas of research focus. Section 4.1 presents a summary pertaining to EPA activities. Section 4.2 presents a summary pertaining to DOD activities. Section 4.3 presents a summary pertaining to DOE activities. Section 4.4 presents research activities in developing monitoring and measurement methods. Section 4.5 presents activities conducted by Los Alamos National Laboratory.

4.1 EPA TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES

EPA is primarily pursuing the development and demonstration of innovative technologies through the Superfund Innovative Technology Evaluation (SITE) program. This program consists of three areas: Demonstration Program, Emerging Technologies Program, and the Measurement and Monitoring Technologies Program. The research activities underway in these areas are described below. These activities have all been included in the development of the technology summary table in Section 2.

4.1.1 Demonstration Program

Table 4-1 summarizes the technologies currently in the EPA demonstration program. The technology breakdown is by the same technology categories used in Section 2 of this report. Table 4-1 also identifies the development status of the individual technologies in terms of whether the technology is a fundamentally new technology or a variation of an existing technology (i.e., applications of existing technologies to new types of contaminants or technical modifications to an existing method).

TABLE 4-1. TECHNOLOGIES IN EPA DEMONSTRATION PROGRAM

TECHNOLOGY	DEVELOPMENT STATUS
GAS COLLECTION	
Active extraction system (VOCs)	Existing technology variation
IN-SITU TREATMENT	
Bioreclamation	Existing technology variation
Solidification/stabilization (PCBs/lead)	Existing technology variation
Vitrification	New technology
Soil flushing (air/steam)	Existing technology variation
LIQUID TREATMENT--BIOLOGICAL	
Biological reactor (3) (PCP/creosote[2], aqueous waste[1])	Existing technology variation
LIQUID TREATMENT--CHEMICAL	
Photochemical (ultraviolet with ozone)	New technology
LIQUID TREATMENT--PHYSICAL	
Liquid/liquid extraction (liquified gases for organics removal)	New technology
Ion exchange (filtration bed using ion exchange-like materials)	Existing technology variation
Sorbents (powdered carbon)	Existing technology variation
Solidification/stabilization (3)	Existing technology variation
Filtration (microfiltration for solids)	Existing technology variation
Freezing (2 - for separation)	Existing technology variation
THERMAL TREATMENT	
Burner development	Existing technology variation
Infrared incineration (2)	New technology
Circulating fluidized bed	Existing technology variation
Plasma arc (2)	New technology
Rotary kiln/thermal desorption	Existing technology variation

TABLE 4-1. TECHNOLOGIES IN EPA DEMONSTRATION PROGRAM
(continued)

TECHNOLOGY	DEVELOPMENT STATUS
SOLIDIFICATION/ENCAPS/FIXATION	
Solidification/stabilization (2 - both oil/organics)	Existing technology variation
SOLIDS TREATMENT	
Chemical/solvent extraction (de-oil sludges and soils)	New technology
Soil washing (for hydrocarbons, PCP, and creosote)	New technology

Reference: U.S. EPA. Superfund Innovative Technology Evaluation (SITE) Program. Hazardous Materials Control Research Institute (HMCRI) Conference. November 28-30, 1989.

As shown by Table 4-1, the majority of the demonstration efforts pertain to variations of existing technologies. Areas of greatest emphasis are in-situ treatment, liquid treatment (physical), and thermal treatment. Solidification/stabilization, as an individual technology variation, appears to have the most activity focus since six different demonstration efforts are under way in that area.

4.1.2 Emerging Technologies Program

Table 4-2 summarizes the technologies currently in the EPA emerging technologies program. This table is compiled similarly to that for Table 4-1. The technologies in Table 4-2 are evenly divided between new technologies and existing technology variations. It should also be noted that two of the new technologies identified in Table 4-2 are similar to two technologies that appear in Table 4-1 (light-induced oxidation and soil washing).

One other technology is in the EPA emerging technologies program but is not shown in Table 4-2. The technology is a constructed wetlands-based treatment approach. This technology uses the geochemical and biological processes inherent in a wetlands ecosystem to remove and accumulate metals from aqueous wastestreams entering the system. The process involves the generation of insoluble precipitates and is being conducted by the Colorado School of Mines.

4.1.3 Measurement and Monitoring Program

The measurement and monitoring program is performed through EPA's Environmental Monitoring Systems Laboratory in Las Vegas, NV. Only two activities are currently under development at this time: immunoassays for toxic substances, and fiber optic sensors for in-situ analysis of hydrocarbons. Immunoassay work has focused on pentachlorophenol in water samples; benzene, toluene, and xylene in soil samples; and nitroaromatic compounds in environmental samples. Fiber optic sensors are under development for trihalomethanes (chloroform) in gas above contaminated groundwater; gasoline; other fuels; and chlorinated hydrocarbons such as trichloroethylene.

TABLE 4-2. TECHNOLOGIES IN EPA EMERGING TECHNOLOGIES PROGRAM

TECHNOLOGY	DEVELOPMENT STATUS
IN-SITU TREATMENT	
Electro Acoustic (for organics)	New technology
Bioreclamation (with oil recovery)	Existing technology variation
LIQUID TREATMENT--CHEMICAL	
Photochemical oxidation (solvents)	New technology
LIQUID TREATMENT--PHYSICAL	
Ultrafiltration (metal removal)	Existing technology variation
Sorption (biological material [algae] to remove metals)	New technology
SOLIDS TREATMENT	
Soil washing	New technology

Reference: U.S. EPA. Superfund Innovative Technology Evaluation (SITE) Program. Hazardous Materials Control Research Institute (HMCRI) Conference. November 28-30, 1989.

4.2 DOD TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES

Ongoing research and development into remediation and treatment technologies is being conducted by the U.S. Air Force and the U.S. Army. Air Force activities largely relate to the cleanup and management of petrochemicals (fuels, solvents). Army activities focus on explosives materials and the destruction (through thermal treatment) of explosive materials and chemical warfare agents. The U.S. Army Corps of Engineers is also examining dredging methods pertaining to contaminated waterways such as contaminated sediments removal, techniques for sediment turbidity control, and methods for solids separation.

Table 4-3 provides a summary of the research and development activities currently underway in DOD for environmental restoration, hazardous waste control, and analytical methods and instrumentation development. The table is structured similarly to Tables 4-1 and 4-2 and the technologies are organized according to the technology categories identified in Section 2.

As shown on Table 4-3, the technologies undergoing demonstration or evaluation cover a wide range of capabilities. However, many of these technology applications represent variations of existing technologies rather than inherently new technologies. It should also be noted that the general technology categories addressed by current DOD efforts includes many of the same activities as EPA in terms of general focus. Areas in common are gas collection, in-situ treatment, liquid treatment--biological, liquid treatment--chemical, liquid treatment--physical, thermal treatment, and solids treatment.

Other pertinent activities being conducted by the DOD include the development of water quality criteria and the development of analytical methods and instruments. The U.S. Army Biomedical Research and Development Laboratory has developed water quality criteria for RDX, nitrocellulose, and nitroglycerin along EPA guidelines. These criteria were developed using health-based approaches in order to establish guidelines for acceptable levels of these contaminants in surface water and to provide a basis for remediation decision making.

TABLE 4-3. DOD TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES

TECHNOLOGY	DEVELOPMENT STATUS
GAS COLLECTION	
Active extraction system (chlorinated solvents and fuels)	Existing technology variation
IN-SITU TREATMENT	
Heating with radio waves (VOC removal)	New technology
Bioreclamation (3 units - TCE, nonchlorinated solvents and fuels, motor oil)	Existing technology variation
LIQUID TREATMENT--BIOLOGICAL	
Bioreactor (2 units - fuel oil, phenol/other chlorinated organics)	Existing technology variation
LIQUID TREATMENT--CHEMICAL	
Photochemical	New technology
Precipitation (heavy metals using xanthate)	Existing technology variation
Ozonation	Existing technology variation
LIQUID TREATMENT--PHYSICAL	
Air stripping (2 units - TCE, volatile organics)	Existing technology variation
SEDIMENTS REMOVAL	
Dredging	Existing technology variation
SOLIDS SEPARATION	
Filtration (explosives)	Existing technology variation
SOLIDS TREATMENT	
Chemical dechlorination	Existing technology variation
Composting (RDX, HMX, TNT)	Existing technology variation
STRUCTURAL CLEANING	
Heating (explosives, chemical agents)	New technology
Mechanical scouring (plastic media blasting)	Existing technology variation

TABLE 4-3. DOD TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES
(continued)

TECHNOLOGY	DEVELOPMENT STATUS
THERMAL TREATMENT	
Rotary kiln (explosives contaminated soils)	Existing technology variation
Industrial boiler	Existing technology variation
Low temperature thermal stripping (VOC removal)	Existing technology variation

Reference: IIT Research Institute. Installation Restoration and Hazardous Waste Control Technologies. AMXTH-TE-CR-88010. Prepared for U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, MD. January 1988.

Two instruments are also under development: a cone penetrometer and an asbestos microscope. The cone penetrometer is used to penetrate soils up to one hundred feet. The penetrometer is equipped to obtain soil gas samples or liquid samples as well as to measure point resistance, frictional sleeve resistance, and soil resistivity. A fiber optic/ultraviolet detector for in-situ analysis of liquids is also under development to be included in the penetrometer. In addition, a portable field microscope system for asbestos material identification has been developed based on a commercially available microscope accompanied by reference slides of asbestos/nonasbestos fibers and a reference manual on sample preparation and microscopic examination.

Over the past few years, the U.S. Army Corps of Engineers has worked with EPA on developing reference manuals on sediments removal and containment techniques as well as methods/technologies for responding to spills (in waterways) of hazardous chemicals that sink in water. Another area jointly explored by the Corps and EPA was methods for separation of solids using the premise that contaminants will partition differently to different sizes of solid materials such as soils or sediments therefore solids separation by sizing will enable separation of more contaminated materials from less contaminated materials. Reports have been prepared for each of the areas above and should be available from the EPA Office of Research and Development or the National Technical Information Service.

4.3 DOE TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES

Research, development, and technology demonstration efforts at the Department of Energy are primarily focusing on remediation of contaminated soils and groundwater. Activities in these two areas represent almost 80 percent of the research and development funding. The remaining 20 percent pertains to underground tanks, soil thermal remediation, site assessments, and decontamination and decommissioning activities.

Table 4-4 provides a summary of the research and development activities underway for technology demonstrations within DOE. The activities cover 11 of

TABLE 4-4. DOE TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES

TECHNOLOGY	DEVELOPMENT STATUS
GAS COLLECTION	
Active extraction system (gasoline hydrocarbons and volatile organic compounds)	Existing technology variation
IN-SITU TREATMENT	
Bioreclamation (refractory organics such as PCBs)	Existing technology variation
Bioreclamation (for mixed wastes-unspecified)	Existing technology variation
Bioreclamation (for uranium mill tailings metals)	Existing technology variation
Bioreclamation (Hg)	Existing technology variation
Bioreclamation (high explosives)	Existing technology variation
Bioreclamation (white rot fungi for organics treatment)	Existing technology variation
Vitrification/joule-heated ceramic melting	New technology
Heating soil	New technology
LIQUID TREATMENT--BIOLOGICAL	
Bioreactor (for TCE)	Existing technology variation
Bioreactor (inorganics and organics)	Existing technology variation
LIQUID TREATMENT--CHEMICAL	
Solvent extraction	Existing technology variation
Catalytic destruction (unspecified)	New technology
LIQUID TREATMENT--PHYSICAL	
Air stripping (volatile organic compounds)	Existing technology variation
Photochemical destruction (solar)	New technology
Electrochemical oxidation (unspecified)	New technology
Reverse osmosis	Existing technology variation
Distillation	Existing technology variation
Electrochemical/microwave denitration	New technology

TABLE 4-4. DOE TECHNOLOGY RESEARCH AND DEVELOPMENT ACTIVITIES
(continued)

TECHNOLOGY	DEVELOPMENT STATUS
REVEGETATION	
Vegetation selection (unspecified)	Existing technology variation
SOLIDIFICATION/ENCAPS/FIXATION	
Solidification of liquid high level radioactive wastes	Existing technology variation
Vitrification	New technology
THERMAL TREATMENT	
Plasma	New technology
Microwave destruction	New technology
SOLIDS Treatment	
Paramagnetic separation of uranium	Existing technology variation
VERTICAL BARRIERS	
Freezing/cryogenic	New technology
WASTE REMOVAL	
Telerobotic retrieval of mixed waste	New technology

Reference: U.S. DOE. Environmental Restoration and Waste Management. Five-Year Plan. DOE/S-0070. Washington, DC. 1989.

the technology categories identified in Section 2, with the greatest emphasis on in-situ treatment methods and liquid treatment systems.

Other areas being addressed within DOE that are related to environmental remediation include:

- In-situ sensors to detect TCE, chloroform, chromium, and nitrates in groundwater
- Systems to detect enriched uranium in the presence of plutonium
- Geophysical methods to detect nonmetallic objects and subsurface voids
- Instruments/data acquisition systems for determining the physical extent of an aquifer
- Development and validation of contaminant transport models, transport models to determine subsurface effects of capping and other in-place remedial actions, and health risk model improvements
- Treatment of radiologically contaminated NaK to produce a salt
- Development of a facility to process chromium wastes from cooling water ponds.

4.4 MONITORING AND MEASUREMENT METHODS RESEARCH AND DEVELOPMENT

Research into the development of new methods for obtaining field measurements of physical systems and contaminant detection is primarily being conducted by federal agencies. The areas of research and measurement system development encompass contaminant-specific detection methods/systems, real-time measurement of contaminants in the field, monitoring system enhancements, transport mechanisms evaluation (hydrological and biological processes), geophysical techniques to map and identify subsurface features, and interpretive analysis of data.

Table 4-5 presents a summary of the current research and development activities pertaining to monitoring and measurement systems. These activities

TABLE 4-5. SUMMARY OF RESEARCH AND DEVELOPMENT ACTIVITIES
FOR MONITORING AND MEASUREMENT METHODS

CATEGORY	MONITORING AND MEASUREMENT METHOD
Site Characterization	<p>The Nature of Redox Potentials in Anaerobic Aquifer Materials</p> <p>Spatial Variability of Hydrogeological Properties of Subsurface Environments</p> <p>Methods for Estimating Spatial Variability of Subsurface Environments</p> <p>Monitoring Strategies for Groundwater</p> <p>Aquifer Test Analysis - Comparative Regional Problems Related to Aquifer Test Analysis</p> <p>Monitoring in Kanst Termes for RCRA Facilities</p> <p>Monitoring in Fracture Rock for Subtitle D RCRA Facilities</p> <p>Comparative Testing of Sampling Equipment and Techniques</p> <p>Seasonal Variability Effects on Well Casing</p> <p>In Situ Fiber Optics</p> <p>Vadose Bone Monitoring with Soil Pore-Liquid Monitoring Devices for Determining Limits of Applicability, and Establishing Installation Procedures</p> <p>Electromagnetic Methods Evaluation for 100 KHz to 10 MHz Frequency Band</p> <p>Development and Evaluation of Surface and Subsurface Geophysical Methods and Strategies for RCRA Site</p> <p>Airborne Electromagnetic Methods to Detect Brine Contamination</p> <p>Geophysical Techniques Survey to Evaluate Subsurface Contamination Associated with Underground Injection Wells</p> <p>Radar System Analysis for Delineating Subsurface Properties</p> <p>Resistivity Survey to Determine Effects of Organics and Clay Bonding on Survey Results</p> <p>Application of Geophysical Methods for Detecting Chlorinated Solvents</p> <p>Geophysical Expert System</p> <p>Background Soil Gas Vapor Value Survey</p> <p>Development of Methods for Storage Tank Lead Monitoring</p> <p>UST Sensor Evaluation</p> <p>UST Long-Term Vapor Monitoring</p> <p>UST Network Design</p> <p>UST Fiber Optic Technology</p> <p>UST Vadose Zone Monitoring</p> <p>Soil Gas Guidance</p> <p>Effectiveness of Drilling Mud as a Plugging Agent in Abandoned Oil and Gas Wells</p> <p>Regional Evaluation of Confining Bed Integrity</p> <p>Methods of Determining Mechanical Integrity of Injection Wells</p> <p>Development of Methods to Identify Sources of Contamination in a Wellhead Protection Area and Develop Relations Between Land Use and Regional Ground-Water Quality</p>

**TABLE 4-5. SUMMARY OF RESEARCH AND DEVELOPMENT ACTIVITIES
FOR MONITORING AND MEASUREMENT METHODS
(continued)**

CATEGORY	MONITORING AND MEASUREMENT METHOD
Transformation	<p>Anaerobic Metabolism of Organic Pollutants in Subsurface Environments</p> <p>Chemical Kinetics of Heterogeneous and Homogeneous Solution Phase Decomposition of Haloaliphatic Compounds</p> <p>Oxy-Radical Processes for Abiotic in Situ Destruction of Organic Pollutants in Aquifers</p> <p>A Recombinant Approach to the Isolation and Characterization of a Primary TCE Degradar</p> <p>Biodegradation of Pesticides in Aquifers</p> <p>Degradation of Monoaromatic Hydrocarbons by Aquifer-Derived Microorganisms Under Various Types of Anerobic Conditions</p> <p>Biodegradation of PCB's in Complex Oily Wastes</p> <p>TCE Biotreatment Demonstration Project</p>
Transport	<p>Theoretical Analysis Solute Transport in Leaky Aquifers During Wastewater Injection Process</p> <p>Regional Screening Model of Virus Transport in Soils and Ground Water</p> <p>Biological Colonization of Hazardous Waste Sites</p> <p>Adsorption of Organic Cations on Soils and Subsurface Materials</p> <p>Facilitated Transport of Hydrophobic Organic Pollutants by Dissolved/Colloidal</p> <p>Partitioning of Hydrophobic Compounds Between Soils and Solutions. Effects of Dissolved Organic Carbon and Surfactants</p> <p>Transport of Inorganic Colloids in "Undisturbed" Subsurface Systems</p> <p>Sorption and Transport of Organic Vapors in Unsaturated Zone</p> <p>Sorption and Transport of Hydrophobic Organic Chemicals in Complex Solvent Systems</p> <p>Multiphase Chemical Transport in Porous Media</p> <p>Solute Transport Phenomena Associated with Residual Saturation of Nonaqueous Phase Liquids</p> <p>Transport of Metal Contaminants in the Subsurface: Sorption/Desorption on Inorganic Colloids and Organic Acid Effects</p> <p>Multiphase Chemical Tranport in Porous Media</p> <p>Solute Transport in Structured Porous Media</p> <p>Solute Transport Under Time-Variant Mobile Phase Composition</p> <p>Hydrazine Transport in Saturated Sandy Soils</p> <p>Sorption/Desorption Kinetics</p>

**TABLE 4-5. SUMMARY OF RESEARCH AND DEVELOPMENT ACTIVITIES
FOR MONITORING AND MEASUREMENT METHODS
(continued)**

CATEGORY	MONITORING AND MEASUREMENT METHOD
Modeling	<p>Parameter Estimation Expert System for Aquifer Restoration Models</p> <p>Efficacy of Land Treatment of Creosote and Pentachlorophenol Containing Wastes and Contaminated Soils</p> <p>Use of Selected Unsaturated Zone Models for Predicting Long Term Fate and Transport of Residual Matrix Organics at Closed Petroleum Refinery Land Treatment Sites</p> <p>Development of Qual/Quant Information Pertaining to Fate/Transport of Residual Matrix Constituents in Contaminated Soils at Closed Sites</p> <p>Development of Predictive Models Pertaining to Impact of Residual Matrix Constituents on Chemical Transport in Contaminated Soil Sites</p> <p>Land Treatment Studies for Selected Food Processing and Pulp and Paper Industry Wastes</p> <p>Swelling Properties of Soil Organic Matter</p> <p>Identification of Sources of Ground-Water Salinity</p> <p>Performance Testing of Ground-Water Models</p> <p>Transport and Fate of Organics From Aircraft Paint Stripping Wastewater</p> <p>Analytical Solutions for Transport of Dissolved Substances with Second-Order Reaction</p> <p>Evaluation of the Validity of Subsurface Contaminant Transport Models</p> <p>Approximate Multiphase Flow Modeling by Characteristic Methods</p> <p>Comparison and Development of Multiphase Flow Models for Monte Carlo Analysis</p> <p>Geostatistical Programs for Managing Soil and Water Contamination</p> <p>User-Friendly Software Development for Decision-Aid Tool Models</p> <p>Expanding Knowledge Bases and Advancing Utility of Ground-Water Models for Management</p> <p>Application of Contaminant Transport Models for Regulatory Decision Making</p>

primarily address environmental restoration-related needs. The table is organized into 4 categories:

- Site characterization
- Contaminant transformation
- Contaminant transport
- Modeling.

The methods development efforts shown in Table 4-5 are fairly equally distributed among the various categories.

Overall, there are differences between the approaches taken by the various federal agencies in methods development. The EPA is attempting to address monitoring and measurement needs from an applied standpoint rather than theoretical. This would enhance current efforts that are focused on conducting site characterization to support remediation decision-making. EPA research is conducted in their laboratories in Las Vegas, NV and Athens, GA. The DOE, on the other hand, has a broader approach involving both theoretical development and demonstration of applied systems. Research and development activities are underway at most DOE facilities to address site-specific issues as well as part of general research efforts.

4.5 LOS ALAMOS NATIONAL LABORATORY RESEARCH AND DEVELOPMENT ACTIVITIES

There are a number of activities ongoing at the Los Alamos National Laboratory that potentially apply to environmental restoration or hazardous waste treatment. These activities were not included in the DOE discussions in Section 4.3, nor the monitoring and measurements discussion in Section 4.4.

Based on discussions with personnel at Los Alamos National Laboratory (LANL) during April 1989 and review of literature provided pertaining to ongoing Laboratory activities, the activities pertinent to environmental restoration and hazardous waste treatment were compiled into a summary by the technology categories identified earlier in Section 2. This summary is presented in Table 4-6.

TABLE 4-6. SUMMARY OF LANL ACTIVITIES PERTAINING TO ENVIRONMENTAL RESTORATION AND HAZARDOUS WASTE TREATMENT TECHNOLOGIES

TECHNOLOGY	DEVELOPMENT STATUS
CAPPING Enhanced landfill cover for semi-arid environments	Existing technology variation
IN-SITU TREATMENT Bioreclamation (explosives, TCE, organic chemicals)	Existing technology variation
LIQUID TREATMENT--BIOLOGICAL Plant cell extraction of metals Bacterial concentration of metals	New technology New technology
LIQUID TREATMENT--CHEMICAL Precipitation (using ferrates)	Existing technology variation
REVEGETATION Evaluation of alternative plant cover suitable for Los Alamos environment	Existing technology variation
THERMAL TREATMENT Supercritical water oxidation Radio-frequency generated plasma Controlled air incinerator (TRU waste) Microwave fluid bed Mobile incinerator (treat flares)	New technology New technology Existing technology variation New technology Existing technology variation

In addition to activities pertaining to technologies, LANL is also involved in a number of activities relating to the development of monitoring and measurement methods applicable to site characterization and data evaluation for site remediation. These activities include:

- Tomography system for soils to measure soil properties and root densities
- Field measurements using laser-induced breakdown spectroscopy (LIBS)
- Field measurements using small mass spectrometer (air, water, soils)
- Transport of depleted uranium
- Advanced drilling techniques
- Field analysis of volatile organic compounds in air, soil, and water using a field mass spectrometer
- Modeling radionuclide behavior in solution to evaluate transport
- Modeling groundwater chemistry and groundwater composition changes over time to support high-level waste repository
- Experimental evaluation of radionuclide migration in unsaturated tuff
- Field LIDAR system for real-time measurement of water vapor in near ground atmosphere for use in evapotranspiration studies as well as to measure concentrations of atmospheric gases and atmospheric pollutants
- Field studies to evaluate effects of scale in modeling.

5. SUMMARY AND RECOMMENDATIONS

Technologies currently under development for environmental restoration and hazardous waste remediation are predominantly variations of existing technologies. The focus of these development efforts appear to involve one of three purposes: (1) to demonstrate the application of a specific technology to a broader or different range of contaminants than previously demonstrated, (2) to optimize areas of poor technology performance (e.g., elimination of corrosion problems, improved air contaminant removal, etc.), or (3) to conduct additional site-specific demonstrations to address a range of environmental circumstances or a range of process chemicals that may be used (e.g., demonstration of different bacterial strains for bioremediation).

Research and development conducted by the Federal government is taking a different focus within each Agency or Department. Within the U.S. Environmental Protection Agency (EPA), efforts are focused on demonstration of technology applications and applied monitoring and measurement methods in order to enhance technology transfer into site remediation. Particular emphasis is placed, where possible, on technologies that will destroy or detoxify wastes thereby reducing the amount of hazardous waste that continues to be sent to long-term land disposal. Hence, EPA is particularly interested in thermal treatment technologies which achieve high destruction rates for organic chemicals, maximum volume reduction, and maximum range of waste types that can be processed.

Within the Department of Defense (DOD), technology development or application is focusing on fuels, propellants, solvents, explosive materials, and chemical warfare agents. Technologies primarily being pursued are methods to remove these materials, predominantly fuels/solvents, from contaminated soils and groundwater, methods to detoxify the above contaminants in-situ, and methods to destroy stockpiled weapons and other supplies such as flares.

The primary waste treatment technologies within the U.S. Department of Energy (DOE) are volume reduction (incineration, compaction/shredding, evaporation) and fixation (solidification). Waste treatment is generally followed by indefinite storage and, in the future, placement in long-term

repositories (WIPP, Yucca Mountain). Much of the emphasis has been on the radionuclides and other heavy metals present in the waste. Current research and development efforts are expanding upon existing waste treatment technologies, as well as exploring applications of existing environmental remediation technologies to mixed waste situations--organic contaminants (solvents) in particular (e.g., air stripping, vapor vacuum extraction, bioreclamation).

The environmental restoration problems facing the DOE are mixed contaminant problems. The sites have a combination of organic and/or inorganic contaminants, as well as radionuclides. In many instances, the technologies used to treat the wastes or contaminated media, or to remediate the environment, are opposing; that is, one technology may readily remove metals and radionuclides but may have no impact on organic contaminants, and vice-versa. As a result, DOE is faced with having to develop technologies that can address both types of contaminants or develop combined technologies into a treatment train to ensure all contaminants are adequately removed or treated. As a result, much of the technology development is focusing on demonstration of existing technologies to mixed waste situations. In addition to the technology demonstrations, there are numerous theoretical research efforts ongoing within the DOE relating to new treatment technologies (predominantly thermal), field or mobile measurement methods/instrumentation, improved measurement methods or instrumentation to provide real-time data that are more accurate than currently obtainable, and more sophisticated transport models to predict contaminant migration.

Based upon the above considerations and the nature of ongoing research and technology-related activities underway at Los Alamos National Laboratory (LANL), the following list of recommendations have been identified.

1. Rapid movement of newly developed technologies and monitoring/measurement methods/instrumentation from theoretical and bench scale research to applied demonstration is critical. This requires obtaining sponsorship for the particular programs. Sponsorship can come from DOE, DOD, or EPA. DOE and DOD can provide funding and sites for the demonstration, but successful demonstration and technology transfer will require experience in applied demonstrations rather than research programs, obtaining pertinent sites

to use for demonstrations, and well-laid-out demonstration plans that focus on applications rather than system research. The EPA has programs underway to demonstrate technologies and to demonstrate new monitoring/measurement methods. The intent of these programs are to promote the development and application of technologies and measurement methods to expand the universe of options currently available in environmental restoration. The programs are structured so that EPA provides assistance in conducting and evaluating the demonstration to ensure that the results are valid and promote technology transfer. EPA can also assist in finding a suitable site. It should be noted that an application for a specific technology needs to be submitted; there are numerous projects already in the system and EPA's ability to conduct additional projects will depend on funding availability.

2. Given that the nature of the problems facing the DOE facilities is different from that faced by EPA, LANL may consider developing a demonstration program with a focus on new technologies for environmental restoration of mixed waste contamination or mixed waste treatment. HAZWRAP currently has numerous activities underway, but funding is limited and is applied to actual remediation activities, as well as demonstrations. LANL could structure a program that focuses on the types of problems present at the DOE/ALOO sites, and those sites could then be utilized as demonstration areas given adequate characterization of the problems beforehand.

3. Activities independent of technology demonstrations can be pursued that will enhance technology transfer from the research laboratories to site applications. One such activity would be the sponsorship of symposia or working conferences that address a specific waste treatment or environmental restoration problem. LANL can arrange, sponsor, and conduct the symposia. For such symposia to be effective, it will be important to include participants from organizations conducting similar efforts, the EPA Office of Research and Development, and interested parties such as DOE or DOD environmental restoration program participants with similar problems or activities. Identifying key participants and representatives who have a decisionmaking role will also be important. The purpose of the symposia would be to facilitate information exchange and to cultivate working relationships to enhance technology transfer.

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