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EPA

Waste Research Strategy

Barrels of waste

Improved disposal techniques

EPA/600/R-98/154
February 1999

Waste Research Strategy

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's Office of Research and Development (ORD) is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The 1997 Update to ORD's Strategic Plan sets forth ORD's vision, mission, and long-term research goals. As part of this strategic process, ORD used the risk paradigm to identify EPA's top research priorities for the next several years. The ORD Strategic Plan thus serves as the foundation for the research strategies and research plans that ORD has developed, or is in the process of developing, to identify and describe individual high-priority research topics. Waste research, particularly for contaminated sites, was identified by the ORD Strategic Plan as an area of high importance that will continue to be a major part of the ORD's research program.

This publication describes ORD's strategy for conducting a waste research program. The strategy identifies broad waste research topic areas that need to be addressed, and prioritizes the research activities associated with each. The strategy is an important planning tool because it makes clear the rationale for selection and prioritization of these research activities. This research strategy is also an important accountability tool, enabling EPA to clearly track progress toward achieving its research goals, as required by the 1993 Government Performance and Results Act.

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Peer Review

Peer review is an important component of research strategy development. The peer review history for this research strategy is as follows:

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Reviewers:	
Hilary I. Inyang, Chair	University of Massachusetts
Stephen L. Brown	R2R2 Risks of Radiation and Chemical Compounds
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Lauren Zeise	California Environmental Protection Agency
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Final Acceptance by ORD:	September, 1998
ORD Executive Lead:	E. Timothy Oppelt, NRMRL

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Acronyms

AST	Aboveground Storage Tank
ASTM	American Society for Testing and Measurement
ATSDR	Agency for Toxic Substances and Disease Registry
ATTIC	Alternative Treatment Technology Information Center
AWMF	Active waste management facility
BDAT	Best demonstrated available technology
CA	[RCRA] Corrective action
CAA	Clean Air Act
CE	Capillary electrophoresis
CEAM	Center for Exposure Assessment Modeling
CEM	Continuous emissions monitor[ing]
CENR	Committee for Environment and Natural Resources
CEPPO	Chemical Emergency Preparedness and Prevention Office
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CRP	Combustion research program
CSCT	Consortium for Site Characterization Technology
DBP	Disinfection by-product
DNAPL	Dense non-aqueous phase liquid
DOD	United States Department of Defense
DOE	United States Department of Energy
DOE-OHER	Department of Energy, Office of Health and Environmental Research
DOIT	Develop Onsite Innovative Technology
DOS	Differential absorption spectroscopy
DQO	Data quality objective
DW	Drinking water
EMAP	Environmental Monitoring and Assessment Program
EPA	United States Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
ESTCP	Environmental Security Technology Certification Program
ETI	Environmental Technology Initiative
ETV	Environmental Technology Verification
FAME	Fatty acid methyl esters
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FRAMES	Framework for Regulatory Analysis and Management of Environmental Systems
FTE	Full-time equivalent
FT-IR	Fourier-transformed infrared
FY	Fiscal year
GAO	General Accounting Office
GC/AED	Gas chromatography/atomic emission detection
GCL	Geosynthetic clay liner
GHG	Greenhouse gas
GPRA	Government Performance and Results Act
GW	Ground water

GWRTAC	Ground-Water Remediation Technologies Analysis Center
HAP	Hazardous air pollutant
HEAST	Health Effects Assessment Summary Tables
HSRC	Hazardous Substance Research Center
HSWA	Hazardous and Solid Waste Amendments
HWIR	Hazardous Waste Identification Rule
IEM	Indirect exposure methodology
INERT	In -Place Inactivation and Natural Ecological Restoration
IRIS	Integrated Risk Information System
ITER	Innovative Technology Evaluation Report
ITVR	Innovative Technology Verification Report
ITRC	Interstate Technology and Regulatory Cooperation working
ITVR	Innovative Technology Verification Report
LDR	Land Disposal Regulation
LIF	laser-induced fluorescence
LIF	Laser-induced fluorescence
LNAPL	Light non-aqueous phase liquid
MACT	Most achievable control technology
MARLAP	Multi-Agency Radiation Laboratory Protocol
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCL	Maximum Contaminant Level
MERA	Multipathway Exposure and Risk Analysis
MITE	Municipal Innovative Technology Evaluation
MS	Mass spectrometer
MSW	Municipal solid waste
MTBE	Methyl-tertiary-butyl ether
NA	Natural attenuation
NAPL	Non-aqueous phase liquid
NCEA	National Center for Environmental Assessment
NECI	National Enforcement Investigation Center
NERL	National Exposure Research Laboratory
NETAC	National Environmental Technology Applications Center
NHEERL	National Health and Environmental Effects Research Laboratory
NIEHS	National Institute for Environmental Health Sciences
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No observed adverse effect level
NPL	National Priorities List
NRC	(a) National Response Center; (b) National Research Council
NRMRL	National Risk Management Research Laboratory
NTP	National Toxicology Program
OERR	Office of Emergency Response and Remediation
OMB	Office of Management and Budget
OPA	Oil Pollution Act
ORD	Office of Research and Development
ORIA	Office of Radiation and Indoor Air
OSP	Office of Science Policy
OST	United States Department of Energy Office of Science and Technology

OSW	Office of Solid Waste
OSWER	Office of Solid Waste and Emergency Response
OUST	Office of Underground Storage Tanks
P2	Pollution prevention
PAH	Polycyclic aromatic hydrocarbon
PBAA	[Office of] Planning, Budgeting, Analysis, and Accountability
PBPK	Physiologically based pharmacokinetics
PCB	Polychlorinated biphenyl
PCE	Perchloroethane
PIC	Product of incomplete combustion
PM	Particulate matter
PRB	Permeable reactive barrier
QA	Quality assurance
QSAR	Quantitative structure-activity relationship
RA	Research area
RCI	Rapid commercialization initiative
RCT	Research Coordination Team
RFA	Request for Application
ROD	Record-of-decision
ROST	Rapid optical screening tool
RTA	Research topic area
RTDF	Remediation Technologies Development Forum
S/S	Solidification/stabilization
SAB	Science Advisory Board
SAR	Structure-activity relationship
SARA	Superfund Amendments and Reauthorization Act
SBIR	Small Business Innovative Research
SERDP	Strategic Environmental Research and Development Program
SFE	Supercritical fluid extraction
SITE	Superfund Innovative Technology Evaluation
STAR	Science To Achieve Results
START	Superfund Technology Assistance Response Team
SVOC	Semi-volatile organic compound
TCE	Trichloroethane
TCLP	Toxicity characteristic leaching process
TIO	Technology Innovation Office
TOE	Total Organic Emission
TOF/MS	Time-of-flight/mass spectrometer
TRD	Technical resource document
TSAP	Treatability Study Assistance Program
TSC	Technical Support Center
TSCA	Toxic Substances Control Act
USGCRP	United States Global Climate Research Program
USGS	United States Geological Survey
UST	Underground Storage Tank
UXO	Unexploded ordinance
VOC	Volatile organic compound
XRF	X-Ray fluorescence

Executive Summary

Chapter 1. Introduction and Background

This document describes a strategy to focus waste research at a national level to reduce the greatest risks to people and the environment. This strategy builds upon the principles set forth in the United States Environmental Protection Agency (EPA) and Office of Research and Development (ORD) strategic plans. Key scientists, engineers, and environmental professionals were engaged in its development to achieve real progress in meeting the needs identified by the Office of Solid Waste and Emergency Response (OSWER), Regional Offices, and other stakeholders and to advance the state of the science. This strategy identifies four research topic areas which correspond to the major waste-related environmental problems (contaminated ground water, contaminated soil/vadose zone, emissions from waste combustion facilities, and active waste management facilities). The strategy prioritizes research activities that ORD should undertake through Fiscal Year 2000 (FY00).

This document is intended to be a "living document" and will be updated as needed to remain current with identified customer needs and the state of the science in waste research. The research needs and priorities described in this document reflect decisions made in the latter half of Fiscal Year 1997 (FY97). ORD's waste research program has continued to evolve since then.

Purpose

The purpose of this strategy is to apply ORD's strategic principles, goals, and ranking criteria to waste problems identified by OSWER and other stakeholders to set priorities for waste-related research. These priorities will be used to focus the efforts of ORD sponsored research (including the use of grants) and form the basis for EPA's coordination with other research organizations and stakeholders.

Structure of the Plan

This report is organized into three chapters. Chapter 1 summarizes the major waste problems facing the United States, associated risks to human health and the environment, and costs of proper management and cleanup. Chapter 2 contains the essence of the strategy. It first lists waste research needs; then describes the four environmental problem areas plus technical support along with related research activities for each topic; and finally presents the ranking of the activities with the rationales for the rankings. The conclusions of the strategy are discussed in Chapter 3 along with outstanding issues that require further evaluation.

Nature and Scope of the Problem

This strategy covers research necessary to support both the proper management of solid and hazardous wastes, and the effective remediation of contaminated waste sites. As such, it responds to two major legislative mandates and large programs within the USEPA — The Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or "Superfund") and their amendments.

The number of existing RCRA waste management facilities and abandoned Superfund waste sites is very large and their potential risks to human health may be significant because of numerous releases of contaminants to the environment.

Abandoned waste sites present a risk to human health. The Agency for Toxic Substances and Disease Registry (ATSDR) found that some heavy metals, volatile organic compounds, and other specific substances occur at levels of health concern in the bodies of exposed people. ATSDR concluded that "uncontrolled hazardous waste sites and unplanned releases of hazardous substances that constitute emergency events are a major environmental threat to human health." (ATSDR, 1996)

Waste management and remediation also have major economic impacts. The average remedial action cost at a Superfund site was about $9 million per site in1996 (U.S. EPA, 1996a). One report concluded that over the next 30 years, the nation as a whole will spend $480 billion to $1 trillion, with a "best guess" of $750 billion, cleaning up sites. (Russell et al., 1991, NRC, 1994).

Chapter 2. Setting Research Priorities

Priorities for waste-related research were set by using the general strategic principles, methods, and criteria identified in the ORD Strategic Plan and then adapting them to waste research topics and activities. This entailed developing a ranking scheme comprised of the following steps: (1) Identify research needs, (2) identify Congressional directives, (3) identify research topic areas and activities, (4) rank research activities, (5) determine how to best accomplish research activities (internal expertise, other areas within ORD, external coordination outside EPA, grants), and (6) prioritize research activities for funding.

Identification of Research Needs

Research needs were identified from two major sources: those identified by the Committee for Environment and Natural Resources (CENR) that were relevant to the EPA's mission, and those identified by the various programs within the Office of Solid Waste and Emergency Response and the Regional waste offices. The latter needs were sorted and categorized as either higher, medium, or lower priority needs. Over one hundred needs were identified during this exercise.

Identification of Congressional Directives

The Congress has directed ORD to conduct certain types of Superfund related activities through legislation and appropriations language. The Superfund Innovative Technology Evaluation (SITE) Program was identified as having Congressional direction included in appropriations' language.

Identification of Research Topic Areas and Associated Research Activities

Four broad research topics were established in two categories that represent the major waste-related research problems:

- Contaminated Sites
  - 1) Ground Water
  - 2) Soils/Vadose Zone
- Active Waste Management and Combustion Facilities
  - 3) Active Waste Management Facilities
  - 4) Emissions from Waste Combustion Facilities

Thirty-nine (39) research activities were identified to address the major research needs in the four research topic areas.

Technical Support to OSWER and the Regional Offices, although not a specific environmental problem, was also identified as a high priority need and a major activity of ORD. Since it is not research, it is not discussed in this document.

Ranking of Research Activities

Using the three sets of ranking criteria identified in the ORD Strategic Plan, ordinal rankings were developed for the research activities within each research topic area. Research activity rankings were first developed based on science criteria only. Uncertainty in risk assessment, efficacy and cost-effectiveness of risk management technologies, and the broad applicability of methods and models were the primary criteria in establishing the science ranking. The final rankings (shown in parentheses next to each research activity in Table ES-1) also considered a number of other non-science factors (this final ranking is referred to as the "Science Plus" ranking). Examples of these other factors include: Administration priorities; CENR research priorities; EPA Program Office priorities; regulatory or legal mandates; Agency priorities; Congressional directives; and FY98 area for new funding.

Determination of How to Best Accomplish Research Activities

Prioritized research activities were considered to determine how to best accomplish the activity and deliver a product to meet the associated "need". Research activities that directly correlated to the expertise, mission and goals of a particular ORD Laboratory or Center were retained for ranking in step six. Activities considered more appropriate for other research programs within ORD or another Federal Agency were noted for coordination as appropriate. Activities that were most appropriate for external grants were likewise noted for coordination into the overall program.

Detailed development and prioritization of research topic areas and activities related to epidemiological studies at waste sites (conducted primarily by the Agency for Toxic Substances and Disease Registry (ATSDR)) and nuclear, defense- and energy-related wastes (activities primarily under the Departments of Energy (DOE) and the Defense of Defense (DoD)) were not done for this version of the Waste Research Strategy. Coordination with ATSDR, DOE, and DoD will be included in greater detail in later revisions to this strategy.

Chapter 3. Conclusions and Issues

Conclusions

There is a large and diverse set of waste research needs that span the spectrum of the risk paradigm. As a result, well integrated research programs are needed for each of the four research topic areas which have the goal of improving our assessment, characterization and risk management capabilities. Also, because there are insufficient resources available to meet all these research needs, the process of ranking research topics and activities is critical.

Four broad research topic areas relating to environmental problems were identified to cover the full range of waste-related research. Priority research activities in each research topic area are:

- Contaminated ground water: The focus of the research activities is on the issues of: improved risk assessment, characterization and remediation of non-aqueous phase liquids (NAPLs); the application and management of natural and accelerated process for subsurface remediation; and the demonstration and verification of innovative characterization and remediation technologies.
- Contaminated soil/vadose zone: The focus of research activities is on the issues of improved exposure and risk assessment of soils, the application and management of natural and accelerated process for remediation, and the demonstration and verification of innovative characterization and remediation technologies in soils and the vadose zone.
- Active waste management facilities: The focus of the research activities proposed for this research topic area is on the science needs related to the Hazardous Waste Identification Rule (HWIR), especially in multimedia, multipathway modeling, and the development or estimation of toxicity values.
- Emission from waste combustion facilities: The focus of research in this topic areas is on the control and monitoring of emissions, emissions fate process and transport modeling, and indirect exposure and risk assessment methods and models.

While there is much uncertainty, debate, and controversy about the health and ecological risks posed by waste sites, there is consensus that the economic impact of current waste management and cleanup practices is clearly large. Within this context, waste research should be viewed as a relatively small but valuable investment to save future expenditures.

Because of the multi-disciplined nature of waste-related research, there are many organizations (across government, industry, and academia) actively involved in sponsoring research activities. In order to maximize efficiency of effort and avoid duplication, special efforts are needed to coordinate and leverage these research programs and activities.

ORD's current research program emphasizes risk management research. There is a need to increase the relative amount of risk assessment research in this program.

Issues

Several issues were identified that may require further attention.

- The lack of risk characterization research
- Future waste strategy development
- Funding strategies

Table ES-1. Selected ORD Waste Research Program Activities.

Research Topic Areas (in Priority Order)	RESEARCH ACTIVITIES BY RISK PARADIGM CATEGORIES					
	Risk Assessment			*Risk Management*		
	Exposure Assessment	Hazard Assessment	Risk Characterization	Remediation & Restoration	Control	Monitoring
Contaminated Sites - Ground Water	- Environmental Fate and Transport Modeling (7)* - GW Exposure Factors / Pathways (21)	- Mixtures Toxicology (26) - Ecological Risk Assessment Methods (38) - Human Dose-Response Models for Mixtures (3)		- Natural Attenuation (2) - Abiotic Treatment of GW (9) - Biotreatment of GW (16) - Containment of GW (17) - Demonstration Verification of Innovative Remediation Technologies (27)		- Subsurface Characterization (6) - Field and Screening Analytical Methods for GW (15) - Demonstration Verification of Field Monitoring Technologies (27)
Contaminated Sites - Soils / Vadose Zone	- Estimating Human Exposure & Delivered Dose (1) - Estimating Soil Intake and Dose - Wildlife Species (3)	- Ecological Screening Tests to Measure the Effectiveness of Treatment (18) - Mixtures Toxicology (34)		- Biotreatment of Soils (3) - Containment of Soils (18) - Demonstration Verification of Innovative Remediation Technologies (27) - Abiotic Treatment of Soils (31) - Oil Spills (36)		- Field Sampling Methods (8) - Field and Screening Analytical Methods for Soils (9) - Sampling Design (22) - Demonstration / Verification of Field Monitoring Technologies (27)
Emissions from Waste Combustion Facilities	- Indirect Exposure Characterization Modeling (13) - Indirect Pathway Risk Assessment Methods (11)	- Movement of Bioaccumulative Chemicals in Food Webs (33) - Dose-Response of Key Contaminants (24)			- Emissions Prevention and Control (12)	- Continuous Emissions Monitoring (CEMs) Methods (23)
Active Waste Management Facilities	- Multimedia, Multi-pathway Exposure Modeling (14) - Environmental Fate and Transport; Physical Estimation (25)	- Developing Provisional Toxicity Values for Contaminants (18)			- Waste Management (36)	- Waste Characterization and Sampling (32)

* Equals the ordinal rank of each research activity across the entire Waste Research Program based on the “Science Plus” ranking factors.

Chapter 1. Introduction and Background

1.1 Research Strategy Purpose, Scope, and Structure

This document describes a strategy to focus waste research at a national level to reduce the greatest risks to people and the environment and to make waste management more cost-effective. This strategy builds upon the principles set forth in the United States Environmental Protection Agency (EPA) and Office of Research and Development (ORD) strategic plans. Key scientists, engineers, and environmental professionals were engaged in its development to achieve real progress in meeting the needs identified by the Office of Solid Waste and Emergency Response (OSWER), Regional Offices, and other stakeholders, and to advance the state of the science. This strategy identifies four research topic areas that correspond to the major waste-related environmental problem: contaminated ground water, contaminated soil/vadose zone, emissions from waste combustion facilities, and active waste management facilities. It also summarizes ORD technical support activities needed to assist stakeholders.

This document is intended to be a "living document" and will updated as needed to remain current with identified customer needs and the state of the science in waste research. The research needs and priorities described in this document reflect decisions made in the latter half of Fiscal Year 1997 (FY97). ORD's waste research program continues to evolve.

1.1.1 Purpose

The purpose of this strategy is to apply ORD's strategic principles, goals and ranking criteria to waste problems identified by OSWER and other stakeholders to set priorities for waste-related research. These priorities will be used to focus the efforts of ORD research laboratories and ORDs external grants program. It will also form the basis for EPA coordination with other Federal agencies.

1.1.2 Scope

This strategy addresses waste-related environmental problems that are of greatest importance from the perspectives of both ORD's research ranking criteria and the program priorities of the OSWER and the EPA Regions. The research activities described herein are those involving the assessment and remediation of contaminated sites (e.g., Superfund, RCRA, corrective action [CA], underground storage tank and oil spill sites), as well as the assessment and control of contaminant releases from waste management (i.e., treatment, storage, and disposal). A fourth important waste management research area, pollution prevention, is addressed in a separate ORD Research Plan (ORD, 1998). Also, contaminated sediments are not explicitly addressed in this document because there is separate ORD research planning activity for this topic (ORD, 1997c). Because it is an integral part of waste management, ORD research planning activities for pollution prevention are summarized in Appendix B.

ORD has significant personnel resources committed to waste technical support and these activities are closely tied to ORD's waste research program. These nonresearch activities are not addressed in this strategy.

This research strategy represents the first comprehensive waste research planning done by ORD. It addresses just research funded in ORD's Waste Research Program. As indicated in Chapter 3, there are other related research activities in ORD which were not considered in the strategy but could be in future strategies.

1.1.3 Structure

This strategy is divided into three chapters. Chapter I describes major waste problems faced by the United States, and their associated risks and risk management costs. This chapter also describes the mission, goals and resources of the ORD Waste Research Program, and the relationship of this research plan to the ORD Strategic Plan. Chapter 2 describes waste research needs identified by ORD, EPA's Program Offices, EPA Regions, and others. Four research topic areas are identified along with a set of research activities that ORD needs to carry out for each topic area. These research activities are then prioritized based upon a waste ranking scheme that uses ORD's strategic planning principles. Chapter 3 provides conclusions from the strategic planning process and summarizes planning issues that remain to be addressed.

There are three appendices. A summary of waste-related environmental research needs is provided in Appendix A in six tables, each describing research needs within one of the six Committee on the Environment and Natural Resources (CENR) risk paradigm categories (discussed in detail later in this chapter). Appendix B provides a summary of other waste-related research programs in ORD, OSWER, other Federal agencies, and the private sector. Appendix C provides additional details to the research ranking process outlined in Chapter 2.

1.2 Nature and Scope of the Problem

1.2.1 Hazardous and Solid Waste Management

In 1965, Congress passed the Solid Waste Disposal Act, the first law to require safeguards and encourage environmentally sound methods for disposal of household, municipal, commercial, and industrial refuse. Congress amended this law in 1970 by passing the Resource Recovery Act and again in 1976 by passing the Resource Conservation and Recovery Act (RCRA). Congress revised RCRA first in 1980 and again in 1984. The 1984 amendments (referred to as the Hazardous and Solid Waste Amendments [HSWA]) significantly expanded the scope of RCRA. The major sections of the statute are:

- Subtitle C, which establishes a program for managing hazardous waste from generation to ultimate disposal.

- Subtitle D, which establishes a program for managing solid (primarily nonhazardous) waste, such as household waste.

- Subtitle I, which regulates toxic substances and petroleum products stored in underground tanks.

Hazardous Waste Facilities

A total of 400,000 facilities have reported generating RCRA hazardous waste in the United States (OSW, 1993a). These waste are regulated under RCRA Subtitle C. About 200 million tons of hazardous waste are generated each year by the largest generators (OSW, 1993b). While far fewer are active today, historically more than 5,000 facilities have been involved in the treatment, storage and disposal of hazardous waste. These facilities, with approximately 100,000 solid waste management units, are potentially subject to RCRA's cleanup program. One study estimates that 2,200 of these facilities will have releases to the environment which are likely to require corrective action (OSW, 1993c). The study indicates that cleanup is driven by ground water and soil contamination, and cancer or non-cancer risks of concern are estimated to occur at between 1,900 and 2,200 hazardous waste management facilities. Roughly 500 of these sites are estimated to have onsite ground water plumes that are over 10 acres in area. Roughly 1,700 of these facilities are projected to have significant contamination. Of the facilities needing cleanup, 350 are estimated to have over 1 million cubic feet of contaminated soil. EPA currently is addressing roughly 1,500 facilities under the RCRA corrective action program (OSW, 1993c).

Solid Waste Management

Some waste streams not managed under RCRA Subtitle C contain constituents that require safe management to protect human health and the environment. Certain large-volume categories of primarily non-hazardous waste include constituents, such as hazardous metals, that may pose serious risks to exposed populations and cause extensive environmental damage. Large-volume wastes include oil and gas industry waste, mining wastes, waste created from fossil fuel combustion, and cement kiln dust. Overall, approximately 6.1 billion tons of these "special" wastes (as defined by the Bevel amendment to HSWA) are generated annually (Laws, 1996).

Further, about 72,000 facilities generate about 7.6 billion tons of other industrial wastes each year (OSW, 1993a). These wastes are managed in 3,300 industrial landfills and at other on- and offsite management units. Information about many manufacturing wastes, which include toxic organic and inorganic constituents, is limited in many cases.

Finally, the evidence from National Priorities List (NPL) shows that even municipal landfills must be managed carefully to prevent risks, since a number of them appear on the NPL. Approximately 209 million tons of municipal solid waste (MSW) are generated annually (OSW, 1995a); 127 million tons are managed in 3,600 MSW landfills in the United States, and the remainder is burned and recycled (OSW, 1996a).

Waste Combustion Facilities

In 1995, the United States incinerated approximately 48 million metric tons of municipal, pathological, and hazardous wastes. There were 211 municipal incinerators, 2,400 medical incinerators, 160 hazardous waste incinerators, 136 industrial furnaces, and 44 cement kilns burning waste materials in various U.S. locations.

Concerns have been raised about emissions from waste combustion facilities for a number of reasons: (1) these facilities can emit significant amounts of toxic contaminants, such as dioxin, furans, mercury, lead, cadmium, and products of incomplete combustion; (2) these emissions become dispersed over large geographic areas that often include large populations or important food products (crops, animal, and dairy products); (3) exposure occurs over several pathways and routes; and (4) high levels of contaminants emitted from waste combustion facilities (e.g., mercury) have been measured in soil and water adjacent to waste combustion facilities.

While there is much scientific uncertainty about the actual risks from contaminants emitted from waste combustion facilities, the factors listed above are enough to influence public perception and the press that these risks are very high and unacceptable. Community protests at facilities such as Waste Technologies Incorporated (WTI) in East Liverpool, Ohio, and at many Superfund sites such as New Bedford Harbor, Massachusetts, and Bloomington, Indiana are examples.

Waste Management Costs

Waste management costs faced by the Nation are significant. It is estimated to cost between $140 and $187 million per year for hazardous waste combustion facilities to comply with proposed Maximum Achievable Control Technologies (MACT) regulations. (OSW, 1995b & 1996b) The potential cost savings from implementing the proposed Hazardous Waste Identification Rule (HWIR) for Industrial Process Wastes, which could exempt some low-hazard wastes from Subtitle C requirements, are estimated at over $100 million annually (OSW, 1995c).

Oil Spills and Leaking Storage Tanks

Spills and leaks of petroleum, petroleum products, and non-petroleum oils are a serious problem affecting nearly every community in the United States. Oil releases threaten public health and safety through contamination of drinking water and through fire and explosions, diminish air and water quality, compromise agriculture, destroy recreational areas, waste non-renewable resources, and cost the economy millions of dollars. Oil spills harm the environment by killing fish, birds, wildlife, and biota; they destroy habitat and food and produce toxic effects in organisms and ecosystems (Laws, 1996).

Particular hazardous constituents of petroleum products have received attention because of their toxicity. They include benzene, MTBE (methyl-tertiary-butyl ether, a fuel additive intended to reduce carbon monoxide emissions from automobiles), and polycyclic aromatic hydrocarbons (PAHs). Benzene is volatile and is a carcinogen. MTBE is considered a potential human carcinogen, is highly water soluble, and may not readily biodegrade. Several of the PAHs found in heavier petroleum hydrocarbon blends (e.g., fuel oils) are carcinogenic or mutagenic (IARC, 1989). The mobility, toxicity, and biodegradability of PAHs varies depending upon the specific compound.

The magnitude and complexity of the problem are reflected in our society's extensive reliance on petroleum, petroleum products and non-petroleum oils to fuel vehicles, heat buildings, generate electricity, produce food, and manufacture a wide variety of goods. The Department of Energy (DOE) reported that approximately 212 million gallons of crude and 584 million gallons of refined petroleum products were produced in, imported to, or exported from the United States in 1994 (Energy Administration, 1995). Our continued national reliance on oil, the broad extent of its use, and the aging of our oil industry infrastructure suggest that oil spills and leaks will continue to be a serious problem in the future.

Much of the nation's petroleum and chemicals are stored in underground storage tanks (USTs). At present, there are over 1.1 million active regulated USTs at over 400,000 sites across the United States. Through September 1996, over 317,000 petroleum releases had been confirmed at about 40 percent of the 750,000 UST facilities in existence in 1990. EPA anticipates an additional 100,000 confirmed releases by the year 2000; 30,000 new releases are reported every year as owners and operators are complying with EPA's 1998 requirements to upgrade, replace, or close substandard USTs. Besides petroleum, there are approximately 30,000 regulated USTs that store hazardous substances.

EPA also regulates about 450,000 aboveground oil storage facilities for prevention, preparedness, and response purposes (OERR, 1991). These facilities each have from one- to several-hundred individual aboveground storage tanks (ASTs); each AST may contain between 661 and 10 million gallons. Petroleum oil and refined products are transported through approximately 1.9 million miles of oil and gas pipeline and 152,000 miles of liquid pipeline in the United States. In addition, large and increasing amounts of non-petroleum oils are produced and widely used in the generation of electricity, in food processing, and in other industries throughout the country.

Annually, between 18,000 and 24,000 AST oil spills are reported to the National Response Center (NRC) and EPA Regions, and between 10 million and 25 million gallons are spilled per year (OERR, 1996a). Many of these spills were larger than 100,000 gallons in quantity; however, depending upon the location, small spills also can cause great ecological damage.

1.2.2 Hazardous Waste Remediation (Superfund)

Problems with our nation's *past* mismanagement of hazardous waste first gained widespread attention in the late 1970s. Incidents such as the contamination of Love Canal in Niagara Falls, New York, sparked widespread concern over hazardous wastes. In response to this growing concern, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in 1980. This law, commonly known as "Superfund," taxed the chemical and petroleum industries and provided broad Federal authority to address the release or threatened release of hazardous substances that may endanger public health, welfare, or the environment. Over five years, $1.6 billion was collected in a trust fund for cleaning up abandoned hazardous waste sites. In 1986, the Superfund Amendments and Reauthorization Act (SARA) was signed into law. SARA increased the trust fund to $8.5 billion over five years and strengthened EPA's authority to conduct cleanup and enforcement activities.

Waste Site Cleanup

EPA's Superfund program has screened hundreds of thousands of sites and release incidents. A measure of the immediacy of problems at sites is reflected in the work of the Superfund emergency response program (the EPA "Removal" program). Nearly 4,300 emergency actions have been initiated to mitigate or eliminate immediate risks to human health and to prevent future risks (OERR, 1996b). These actions have reduced potential acute risks leading to death and injury, from explosions, fire, and toxic vapor clouds.

Approximately 40,000 sites have been identified as potential candidates for the Federal Superfund remedial program (OERR, 1996b). To date, about 1,300 highest priority sites have been assigned to the NPL, and additional sites are being studied to determine whether NPL listing is necessary. The NPL sites represent approximately 3 million acres in total area. The problem is not static; new sites are constantly being proposed to EPA and the states. The size of this unaddressed problem was recently estimated by the General Accounting Office (GAO), which projected that a cap on the federal NPL might leave the states with 1,400 to 2,300 NPL-caliber sites to clean-up, at a total cost of $8.4 to $19.9 billion (Sands, personal communication, 1996).

The seriousness of contamination at Superfund sites is exhibited by actions taken to remove populations from the immediate threat of contaminants at sites. The Superfund program has relocated, temporarily or permanently, almost 15,000 residents. It also has provided alternative drinking water supplies to approximately 350,000 people (OERR, 1996c).

Federal facilities represent another important class of waste disposal sites where serious contamination has been identified. An estimated 61,000 potential hazardous- substance release sites exist at over 2,000 federal facilities (U.S. CEQ, 1993).

Contamination at remedial sites involves substances of significant concern to EPA both because of their cancer and non-cancer hazards. For example, lead and PCB contamination are common problems addressed by the remedial program. Unsafe concentrations of benzene, several chlorinated solvents, mercury, creosote, toluene, and other highly hazardous substances often are encountered. The Superfund program also confronts risks posed by substances such as DDT or chlordane that no longer are produced commercially but persist in the environment.

The existence of a hazardous contaminant in the environment does not in itself demonstrate an actual or potential threat to human health by exposure. There are reasons for serious concern. ATSDR estimates that about 11 million people live within one mile of the 1,200 NPL sites studied (Williams and Lybarger, 1996). In addition, approximately 68 million people live within four miles of these NPL sites and approximately 65 percent of the sites have identified ground water contamination problems (Sands, personal communication, 1996). Further, ATSDR (1996) also reported:

> Exposure assessment studies conducted by ATSDR during this reporting period show that some heavy metals, volatile organic compounds, and other specific substances occur at levels of health concern in the bodies of exposed people. Compounds such as lead, arsenic, mercury, polychlorinated biphenyls, and bromides are found at significant levels in people near some hazardous waste sites. Taking these health findings in the aggregate, ATSDR concludes that uncontrolled hazardous waste sites and unplanned releases of hazardous substances that constitute emergency events are a major environmental threat to human health. Although there remain significant gaps in the scientific database on the extent of human exposure to hazardous substances released from sites, and key toxicological data gaps still exist, progress has been made in better characterizing both the exposure and toxicity data bases. The human health finding accrued to date support the need for interdicting human exposure and mitigating toxicity of hazardous substances released from hazardous waste sites and similar sources of exposure.

EPA has defined an acceptable human health risk range for carcinogens (10^{-4} to 10^{-6} excess cancer risk) and a threshold of concern for non-carcinogens (hazard index of 1) for Superfund sites. At most Superfund sites, risks exceed acceptable levels, and action is taken. The cancer risk exceeded EPA's acceptable range in 80 percent of sites where decisions were made in 1991, and it exceeded 10^{-2} at approximately 25 percent of these sites. Another recent finding is that non-carcinogenic risk represents a very significant portion of the risk addressed by the Superfund program. The hazard index exceeded 1 at 75 percent of the 1991 sites for which decisions were made. At half of these sites, the hazard index was above 10, and at 15 percent of the sites it was above 100. Data from Superfund risk assessments completed from 1989 to 1995 at 380 Superfund sites show similar results (Walker, 1995; OERR, 1995).

The costs of assessment and remediation of contaminated sites are large. The average remedial action cost alone at a Superfund site remediation is about $9 million per site (U.S.EPA, 1996a). A 1994 report by the National Research Council (1994) on ground water cleanup reviewed available data on the national cost of contaminated site remediation:

> In part because of the wide variation in contaminated sites and because the total number of sites is uncertain, estimating the total national costs of cleaning up contaminated ground water is extremely difficult. One recent, widely publicized report concluded that over the next 30 years, the nation as a whole will spend $480 billion to $1 trillion, with a "best guess" of $750 billion, cleaning up . . . sites. With 90 million households in the nation, this represents a cost of $8,000 per household. Another recent report concluded that by the year 2000, the nation will be spending nearly $24 billion per year complying with requirements for hazardous waste and underground storage tank cleanup under RCRA and site cleanups under CERCLA. Some contest the accuracy of such cost estimates because of the high level of uncertainty associated with the magnitude of the contamination problem and the large number of assumptions underlying the estimates. Nevertheless, the potential enormity of the costs has fueled the debate about whether the benefits the nation will receive from ground water cleanup at hazard waste sites justify the costs.

Improved site characterization can reduce cleanup costs, by millions of dollars, by better defining the volumes of soils that really need to be remediated. At a site in Missouri, $6 million was saved because an improved ORD sampling design for the site more accurately defined the location of significant contamination. Similarly, millions of dollars can be saved by the application of innovative remediation technologies. A 1996 analysis of 46 Records of Decision (RODs) that applied innovative technologies of the type tested in the EPA Superfund Innovative Technology Evaluation (SITE) program showed an average of $30 million saved per ROD compared to the cost of using conventional cleanup technologies (Gatchett, 1998).

Accidental Releases

In 1995, approximately 17,000 accidental release reports involving chemicals were made to the National Response Center (NRC, 1996). These accidents occur during the transport of a chemical, in the manufacturing process, or while the chemical is being employed as an end product.

As a way of understanding the magnitude of the problem, the National Environmental Law Center (1995) has calculated "worst case scenarios" for accidents involving approximately 10,000 U.S. manufacturing companies. They have concluded that close to 45 million Americans live in zip codes containing facilities with vulnerable zones extending outward more than three miles from the facility. This analysis may underestimate potential exposure, since it does not address populations vulnerable to transportation accidents.

1.3 Waste Research Program Mission, Goals and Resources

1.3.1 Mission Statement

The mission of the ORD Waste Research Program is to:

- **Perform research and development** to identify, understand, and solve current and future problems related to the handling and disposal of hazardous wastes and the characterization and remediation of contaminated waste sites.
- **Interpret and integrate scientific information** to help organizations make better decisions about handling and treating of hazardous wastes.
- **Provide national leadership** in addressing emerging hazardous waste issues and in advancing the science and technology of risk assessment and risk management as they relate to hazardous wastes.

1.3.2 Waste Research Goals

The five scientific and technological goals of this research plan are:

- To advance the science of risk assessment to support hazardous waste management and remediation of contaminated sites, including:
  - Understanding the effects of exposures to hazardous wastes on human health and ecological systems.
  - Developing processes for predicting and measuring exposure to humans and ecological systems, and uncovering the processes leading to those exposures.
  - Estimating risk and characterizing and communicating those estimates.
- To develop, demonstrate, and evaluate more cost-effective, innovative technologies for controlling of hazardous wastes, site characterization, and remediation.
- To advance the science of monitoring and predicting environmental concentrations and effects and the fate and transport of toxic material.
- To provide technical assistance to ensure that innovative approaches to site assessment, characterization, and remediation are applied in a consistent and effective manner.
- To lead in areas of ORD capability by providing, developing, and maintaining a highly respected research program that reflects the concerns of stakeholders.

1.3.3 Relationship to Agency Goals

Recently Congress passed the Government Performance and Results Act (GPRA) requiring each agency to submit an annual performance plan covering each program activity set forth in the agency's budget. In response to GPRA, EPA developed programmatic goals, objectives and subobjectives. OSWER has developed a "Safe Waste Management" goal that has two objectives (contaminated waste sites and waste management) for which ORD has developed subobjectives:

- ORD Safe Waste Subobjective 1.6 - Contaminated Sites.
- ORD Safe Waste Subobjective 2.6 - Active Waste Management Facilities.

The research topic areas described in Chapter 2 of this research strategy are divided between these two subobjectives.

1.3.4 Relationship to ORD's Strategic Plan

ORD has developed a strategic process for planning research that follows the risk assessment paradigm (Figure 1-1) and sets research priorities (ORD, 1997a). Figure 1-2 shows the steps recommended to translate the strategic guidance of ORD's Strategic Plan into ORD research activities. The first step is the development of research science plans (or research strategies). Each such plan or strategy deals with a selected research topic, such as waste, and is expected to:

- Describe the major research components and directions ORD will pursue over the next few years.

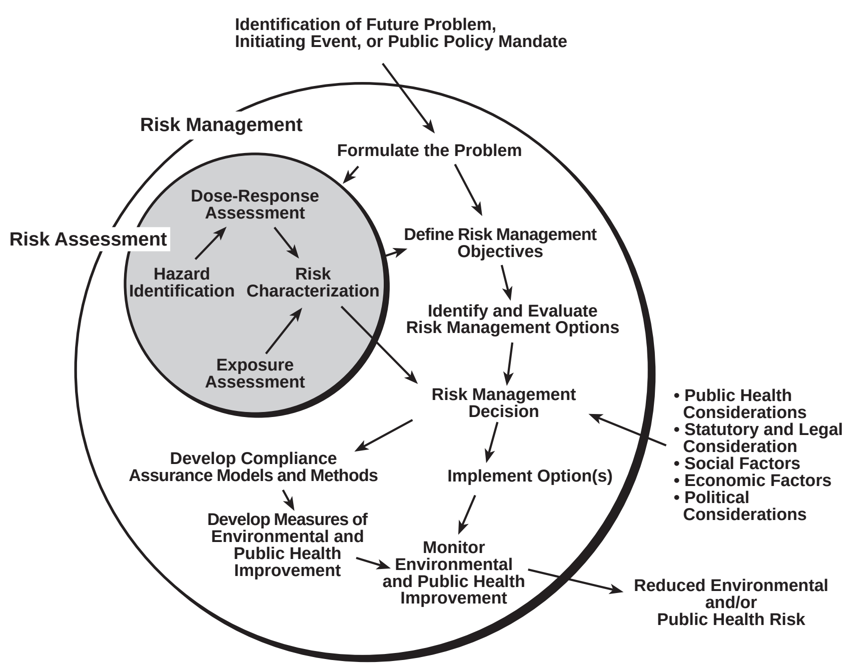


Figure 1-1. A risk paradigm used by the Office of Research and Development (Source: ORD, 1997a).

- Describe how these components fit into the risk paradigm.
- Delineate the major outputs expected to be produced over the next three years.

The ORD Strategic Plan also identifies general goals, long-term objectives, and activities to meet these objectives.

The Waste Research Strategy contains these components of a research strategy and is consistent with, and builds upon, the goals and objectives of the ORD Strategic Plan.

1.3.5 Prior Research Strategies

Previously, a number of research plans and strategies related to hazardous waste have been produced and they contributed to the identification of research needs in this strategy.

CENR National Strategy

The most current and important federal strategy was the President's National Science and Technology Council through its Committee on the Environment and Natural Resources

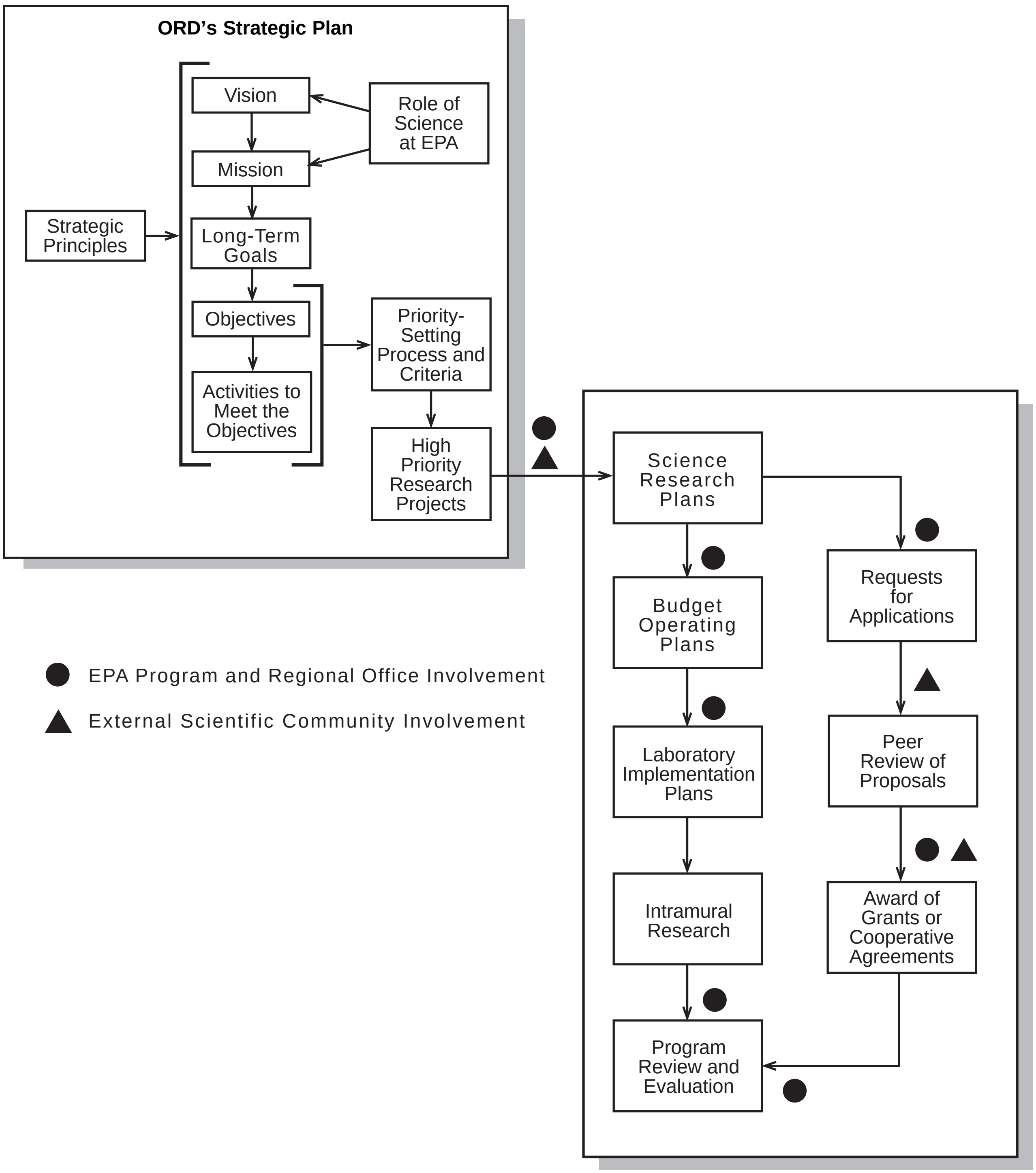


Figure 1-2. Translating ORD's Strategic Plan into a research plan (Source: ORD, 1997a).

(CENR). This group published *A National R&D Strategy for Toxic Substances and Hazardous and Solid Waste* (CENR, 1995). This is the first consensus Federal "framework" for research in this area.

The CENR strategy has adopted "risk" as the organizing theme. Consequently, the three sections of that strategy are: Risk Assessment; Managing Risks from Toxic Substance and Wastes; and, Social and Economic Aspects of Risk Management. Each of these is further divided as shown below:

- Risk Assessment
  - Hazard Assessment
  - Exposure Assessment
  - Risk Characterization
- Risk Management
  - Pollution Prevention
  - Control
  - Remediation
  - Monitoring
- Social and Economic Aspects of Risk Management

For each of the three major sections, the CENR strategy discusses a conceptual framework, the current state of understanding, research priorities, and a set of milestones for 1995 through 1999.

The ORD Waste Research Strategy uses the CENR structure to organize research needs and proposed research activities. (The CENR "Hazard Assessment" research category incorporates both hazard identification and dose-response assessment activities in ORD's risk paradigm.) Also, the CENR report is one source of research needs addressed by this Waste Research Strategy. Adopting the CENR framework and considering priority CENR research needs, helps to insure consistency of Waste Research Strategy with other Federal waste research programs.

ORD Strategic Issue Plans

During the early 1990s, ORD conducted research planning by developing topical "issue plans." The four issue plans most relevant to the current waste research planning activity are the Hazardous Waste Issue Plan (ORD, 1993a), the Surface Cleanup Issue Plan (ORD, 1993b), the Bioremediation Issue Plan (ORD, 1993c), and the Ground Water Issue Plan (ORD, 1993d). These issue plans summarize much of the ORD perspective on waste research priorities at the beginning of the development of this document.

1.3.6 Research Program Funding Resources

In Fiscal Year 1998 (FY98) ORD had a total of $23.2 million available to its Waste Research Program to conduct risk assessment and risk management research on contaminated sites and active waste management facilities. These funds were available for: a) the conduct of waste research by EPA staff (excluding salaries, travel, etc.); and, b) extramural grants programs directly administered by the EPA. Of this total, contaminated sites research was funded at $21.7 million with approximately 80 percent of the funds being applied to risk management research and 20 percent of the funds being applied to risk research. Active waste management facilities research was funded at $1.5 million, with an approximately 15/85 split of funds between risk management and risk assessment research.

Chapter 2. Setting Research Priorities

Research needs invariably exceed resources available to support them, and decisions must be made about which needs to pursue. This section describes how the selection and prioritization of waste research fits into ORD's strategic planning process, what are the waste research needs, how waste research priorities were developed, and what are the resulting priorities.

2.1 Process for Ranking Research

The ranking of waste research builds upon ORD's Strategic Plan (ORD, 1997a) by refining the priority setting process and adding some additional criteria based upon waste-specific strategic considerations.

2.1.1 ORD Strategic Planning Process

In ORD's Strategic Plan (Figure 2-1), potential research topics are evaluated by determining whether they are mandated (by the Executive, Congress, or the courts) and if they are consistent with ORD's mission and goals. Topics that remain are ranked and a determination made as to whether ORD can make a significant research contribution to these areas. The three sets of criteria for evaluating and ranking potential research topics are: Human Health and Ecological Health Criteria, Methods/ Models Criteria, and Risk Management Criteria (Table 2-1). These criteria are to be applied to research topics to compare their potential to support effective risk reduction.

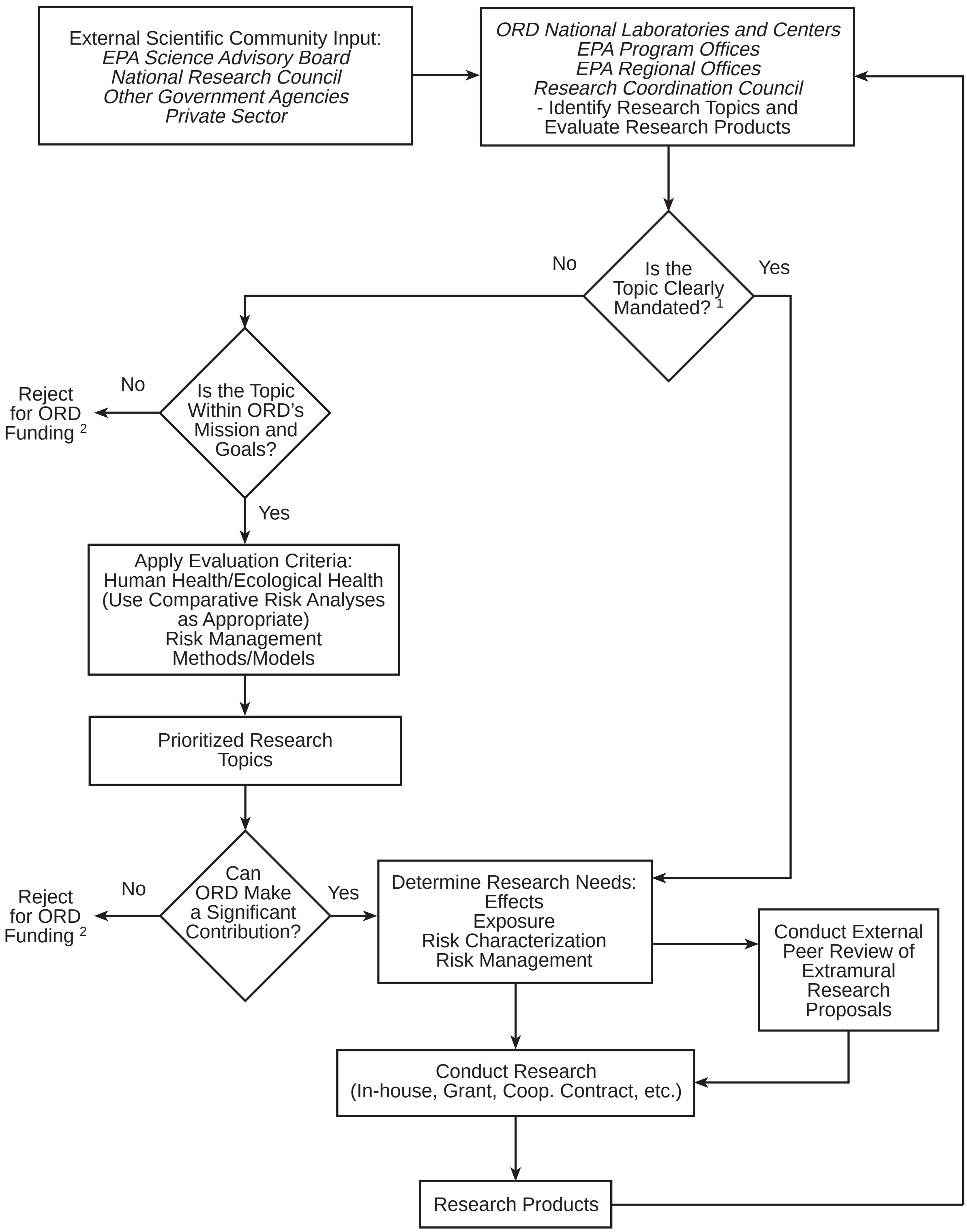
2.1.2 Waste Research Strategic Planning Process

To facilitate the identification and ranking of waste-specific research, ORD developed a process called the Waste Research Ranking Scheme (Figure 2-2). ORD first identified waste research needs based on several sources, resulting in a lengthy list of varying degrees of specificity. Preliminary determinations were made on who should address these needs, another Federal agency, other ORD research programs, or the ORD Waste Research Program itself. Based on an evaluation of these research needs, ORD identified major waste-related environmental problems that it could address and defined these as "research topic areas" (RTAs). The RTAs in the Waste Research Strategy are: Contaminated Sites - Ground Water, Contaminated Sites - Soil/Vadose Zone, Emissions from Waste Combustion Facilities, and Active Waste Management Facili-

Table 2-1. ORD criteria for evaluating and ranking potential research topics.*

Human Health and Ecological Health Criteria	Methods/Models Criteria	Risk Management Criteria
• What type of effect would the research investigate / mitigate and how severely might this effect impact humans or ecosystems? • Over what time scale might this effect occur? • How easily can the effect be reversed, and will it be passed on to future generations? • What level of human or ecological organization would be impacted by the effect? • On what geographic scale might this effect impact humans or ecosystems?	• How broadly applicable is the proposed method or model expected to be? • To what extent will the proposed method or model facilitate or improve risk assessment or risk management? • How large is the anticipated user community for the proposed method or model?	• Have the problem's source(s) and risk been characterized sufficiently to develop risk management options? • Do risk management options (political, legal, socioeconomic, or technical) currently exist? • If so, are they acceptable to stakeholders, implementable, reliable, and costeffective? • Could new or improved technical solutions prevent or mitigate the risk efficiently, cost-effectively, and in a manner acceptable to stakeholders? • Are other research organizations (e.g., agencies, industry) currently investigating / developing these solutions or interested in working in partnership with ORD on the solutions?

* Criteria used as "Science" Ranking Criteria in this strategy.



[1] If so, EPA may have no discretion to reject or delay this research.
[2] EPA program offices and regions may still choose to fund, using ORD labs, grants, contracts, etc., or a research sourse outside of ORD.

Figure 2-1. Office of Research and Development strategic planning process (Source: ORD, 1997a).

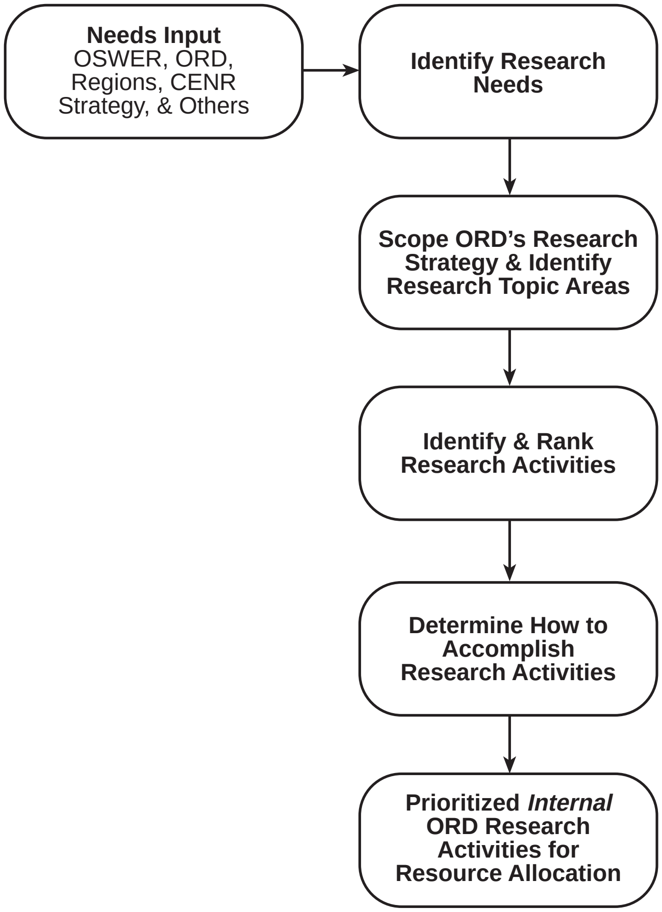


Figure 2-2. ORD waste research ranking scheme.

ties. All of these RTAs are discussed in detail later in this chapter. For each RTA, ORD identified a set of "research activities" that needed to be carried out to address uncertainties associated with the particular environmental problem. These research activities were evaluated and ranked within each RTA using the same three sets of criteria identified in Table 2.1. These criteria were considered when ranking the research activities and formed the basis of the "science" ranking criteria (see Section 2.2.3).

Throughout this process, research needs and research activities were organized using a slight modification of the risk paradigm organizing principles from the CENR strategy. Six of the CENR categories were used: three were risk assessment categories: hazard assessment, exposure assessment, and risk characterization and the other three were risk management categories: control/management, remediation, and monitoring. Pollution Prevention and Social and Economic Aspects of Risk Management were not used since they are outside the scope of this research plan.

2.2 Application of the Waste Ranking Scheme

The purpose of this section is to describe what research needs were identified, how the research priorities were developed, and what the resulting priorities were. The multi-step approach to waste ranking is outlined in Figure 2-2 and discussed below.

2.2.1 Identify Research Needs

Research needs were identified from three sources: 1) those identified by the CENR that were relevant to the EPA's mission; 2) those identified by the individual Program and Regional Offices; and 3) those identified by ORD. The majority of research needs are based on material provided by OSWER at the Waste Research Program Review in December 1996. Additional information on research needs from all three sources is provided in Appendix A.

The OSWER and Regional research needs are summarized in Table 2-2. Generally, OSW identified hazardous waste combustion, multimedia science, waste technology, and pollution prevention/derived waste products as their four highest priority areas. They also identified human health sciences, ecological risk, socioeconomic, methods, and technical assistance for corrective action as high priority. OERR's highest priorities for support and research have been consistently site-specific technical support, risk assessment support, innovative site characterization technologies, and site remediation/cleanup technologies. Research priorities from OUST are focused on corrective action. The Technology Innovation Office (TIO) identified priorities related to continuation of the Superfund Innovative Technology Evaluation (SITE) Program and research in the areas of bioavailability and natural attenuation. The Chemical Emergency Preparedness and Prevention Office (CEPPO) has identified research related to the accidental large-scale release of gases and liquids and support of the DOE spills facility in Nevada. The Regional Offices have identified needs related to indirect exposure from waste combustion, natural attenuation, development of measurement and risk assessment tools, site-specific technical support and training courses and seminars as their highest priorities.

2.2.2 Scope ORD's Research Strategy and Identify Research Topic Areas

In determining the scope of research to be addressed in this strategy, ORD limited itself to waste streams and related environmental problems that are of significant priority to the Agency, particularly OSWER and the Regions. This decision recognizes that there are numerous high priority waste-related environmental problems which the Agency has to address and ORD has only limited resources to conduct related research. As a result, the research needs addressed by this strategy fall into two broad categories of environmental problems: contaminated sites and active waste management facilities.

For contaminated sites the principal emphasis is on those within the Federal Superfund, RCRA Corrective Action, and UST programs. Environmental problems from oil spills are also considered. Sites in these Federal programs are usually the most contaminated in the nation, and results of research on them should have wide applicability to other sites, such as those

Table 2-2. Summary of major program office and regional research and support needs.

Program Office	Higher Priority Needs	Medium Priority Needs	Lower Priority Needs
OSW	Hazardous Waste Combustion, including - Dioxin/Furan Emissions - Surrogates and CEMs for HAPs, Dioxins, and Furans - Technical Support for Combustion Issues - Speciation Methods for PICs - Air Deposition Models - Indirect Exposure -- Bioaccumulation through the Food Chain	Human Health Sciences - IRIS/HEAST Data Base Updates - Alternative Endpoints - QSAR/SAR Methodology Development Ecological Risk - Ecotoxicity Screening Levels, Bioavailability Mechanisms - Improved Screening Tools	
	Multimedia Science, including - Improve Multimedia Models and Data Bases - Validation / Verification of Fate and Transport Models (Multimedia and Indirect Exposure Portions) - Subsurface Biodegradation Rates - Enhance Subsurface Models to Include Fractured Flow	Socioeconomic - Risk Tolerance Thresholds for Exposed Populations - Engineering/Costing Support - Contingent Valuation	
	Waste Technology, including - Stability/Bioavailability of Constituents in Waste Derived Products - Chemistry of Waste Leaching -- Improve TCLP - Treatment Alternatives for Mercury - Efficacy of Waste Solidification / Stabilization Technologies - Natural Attenuation, Permeable Reaction Barriers - Innovative Site Characterization Technologies	Methods - Speciation of Arsenic and Selenium - Pesticide Methods Development (GC/AED) - PAHs by Capillary Electrophoresis Technical Assistance for Corrective Action	
	Pollution Prevention / Waste Derived Products, including - Source Reduction / Recycling for Processes that Generate the Most Toxic Wastes - Technologies for Reducing Barriers to Recycling - Source Reduction for Combustion Wastes		

Table 2-2. (Continued).

Program Office	Higher Priority Needs	Medium Priority Needs	Lower Priority Needs
Regions (RCRA Needs)	- Particle Size Distribution Testing Methods in Support of Air Modeling - Develop Ecological Risk Screening Values for Various Exposure Scenarios - Natural Attenuation for Chlorinated Solvents	- Improve the Total Organic Emission (TOE) Test Methods - Enhance Dry Gas Air Dispersion Models - Enhance Guidance on Synergistic Effects When Deal with Mixtures (Low Priority) - Fill Data Gaps in IRIS and HEAST Databases - Ecological Toxicity Mechanisms of Action for Endocrine Disruptors - Improved Biotransfer and Uptake Factors for Risk Assessments - Modify TCLP to Address Oily Wastes - Develop a Test for Corrosivity of a Solid - Develop a Test for Ignitability of a Solid - Develop a Test to Evaluate the Permanence of Stabilized Wastes	
OERR	Site Specific Technical Support - Technical Support Centers - Environmental Photographic Interpretation Center (EPIC) - START - Center for Exposure Assessment Modeling) - Establish a Technical Support Center for Ecological Risk Assessment - Technology Transfer -- Seminars and Courses - Program Office Support -- Presumptive Remedies, Soil Screening, etc. - Technology Transfer - ATTIC, etc.		
	Site Remediation Research - Ground Water Containment - DNAPL Remediation Methods - Subsurface Reaction Walls - Phytoremediation		
	Oil Spills Research - Technical Correction on Swirling Flask Test for Dispersants - Develop Surface Washing Effectiveness Test	Oil Spills Research - Develop Bioremediation Strategies - Ecological Impacts of Countermeasures	

Table 2-2. (Continued).

Program Office	Higher Priority Needs	Medium Priority Needs	Lower Priority Needs
OERR (cont.)	Site Characterization Research - Ground Water DNAPL Characterization - Natural Attenuation/in situ Bioremediation Site Characterization and Process Research - Ground Water Modeling	Site Characterization Research - Analytical Methods for Bioaccumulative Chemicals - Analytical Methods and QA for Complex Mixtures	
	Risk Assessment Research - Ecological Significance - Benefits versus Habitat Destruction - Dermal Toxicity Values - Bioavailability of Metals and Organics - Soil - Improved Exposure Assessment - Improved Dose-Response Assessment - Pb Uptake / Models - Dermal Exposure Model	Risk Assessment Research - Weight of Evidence Approach for Ecological Effects Cleanup Levels	
Regions (Superfund Needs)	- Site-specific Technical Support - Training Courses and Seminars - Remediation Design and Field Construction Support - Develop Alternative Approaches using Immunoassay and Bioassay Tools - Develop Ecologically-based Screening Values		
OUST	- Natural Attenuation - MTBE Treatment - Fate and Transport Models for Risk-based Corrective Action		
TIO	Superfund Innovative Technology Evaluation (SITE) Program - Remediation Technologies - Monitoring / Characterization Technologies Consortium for Site Characterization Technologies Bioavailability of Families of Contaminants Metrics for Evaluation of In situ Technologies Models to Predict the Efficacy of Natural Attenuation		
CEPPO	- Support DOE Spill Test Facility Hazard Analysis Support - Large-scale Releases of Gases and Liquids		

in state clean-up programs and Brownfields sites. ORD divided the contaminated site issues into two RTAs: Contaminated Sites - Ground Water, and Contaminated Sites - Soils/Vadose Zone.

The selection of two contaminated site RTAs recognizes that there are a number of distinctions in the technical problems that need to be addressed in the saturated zone compared to the unsaturated zone.

ORD will not address certain types of contaminants and waste streams because they are outside the principal areas of expertise, are being handled by other Federal agencies, are not an environmental priority or are not readily addressed by a research program with only modest resources. Radionuclides are not being addressed because ORD lacks expertise in this area and DOE is doing research related to these pollutants. Similarly, DOD has major research programs on remediation of sites contaminated with munitions wastes. This strategy also does not address high volume wastes (e.g., mining wastes) that are excluded from RCRA either by statue or by RCRA regulations. It is important to note, however, that many of the research issues addressed by the strategy are important to these excluded waste types. For example, research on metals contamination should prove applicable to radionuclide contaminated sites, mining wastes, and utility wastes.

ORD also decided to limit its research on environmental issues associated with solid waste management. ORD has conducted relatively large research programs in this area in the past, but since the early 1990s, work has been reduced in response to guidance from OMB and OSWER. As a result, a decision was made to focus on a few areas of high priority to OSWER: waste combustion, multipathway assessments, and - to the extent ORD has expertise solid waste - management and characterization issues. This resulted in two waste management research topic areas: Waste Combustion Facility Emissions, and Active Waste Management Facilities.

Such choices make sense within the context of the risk paradigm, because solid waste regulations have been in place since the 1980s, and, with limited exceptions, solid waste management approaches at active waste management facilities are already minimizing risks at reasonable costs.

2.2.3 Identify and Rank Research Activities

Research activities were identified that would address the major research needs within each RTA (Table 2-3).

The research activities within each RTA were then ranked in a two-step process, details of which are provided in Appendix C. First, a "Science" ranking was conducted using the three sets of criteria identified in the ORD Strategic Plan (Table 2-1). These criteria were used for establishing priorities according to the three simplified graphic representations shown in Figure 2-3. Those research activities that fall within the upper right corners were considered to be high priority, those that fall in the top left and bottom right corners were considered medium and those that fall in the lower left corners were considered low. These "Science" rankings were then adjusted to take into consideration a number of non-scientific factors, yielding a "Science Plus" ranking of research activities *within* each RTA. Examples of these non-scientific factors include: Administration priority; CENR research priority; EPA Program Office and Regional Offices' priorities (Table 2-2); regulatory or legal mandates; EPA priorities; Congressional directives; and FY98 areas for new funding.

2.2.4 Determine How to Accomplish Research Activities

Research activities were examined to determine if they are best accomplished through the expertise of the waste research program at ORD Laboratories and Centers or through other means. Coordination with the Hazardous Substance Research Centers (HSRCs), other research programs within ORD, other Federal research programs, Program Office funded research activities, or independent private sector research programs will be sought when these mechanisms are more appropriate due to the particular expertise of these groups or due to constraints on available ORD waste research resources.

Ecosystem effects and chemical toxicity testing for human and ecological endpoints are two areas to be leveraged with other programs. Ecosystem effects are most appropriately accomplished as part of ORD's Ecosystem Protection Program. Chemical toxicity testing for human and ecological endpoints - the routine application of standard toxicology protocols for the development of human and ecological toxicity values - could be best accomplished through coordination with the National Institute of Environmental Health Sciences (NIEHS) National Toxicology Program. As a result, these two research activities - Ecological Effects and Chemical Toxicity Testing - were removed from further consideration for funding under the Waste Research Program.

Congress established the HSRCs to conduct waste research through regional academic consortia. The HSRCs are conducting fundamental and applied research in many of the same areas as ORD; therefore, ORD needs to coordinate closely its research to ensure it does not duplicate that of the HSRCs. The HSRCs are discussed in further detail in Appendix B.

In addition, there are major waste related research programs being conducted by the ATSDR, NIEHS, DOD, and DOE as described below.

Superfund legislation mandates that ATSDR and NIEHS perform research in specific areas. ATSDR has been charged to perform health assessments at waste sites to assess whether exposure has occurred and to determine the potential impact of any exposure. ATSDR has also been directed to conduct applied substance-specific research to fill data gaps identified by its toxicological profiles. NIEHS has been directed to establish a university-based basic research program. This is a mature program that conducts research in the detection of hazardous substances in the environment, evaluation of health effects, assessment of risk, and site remediation methods.

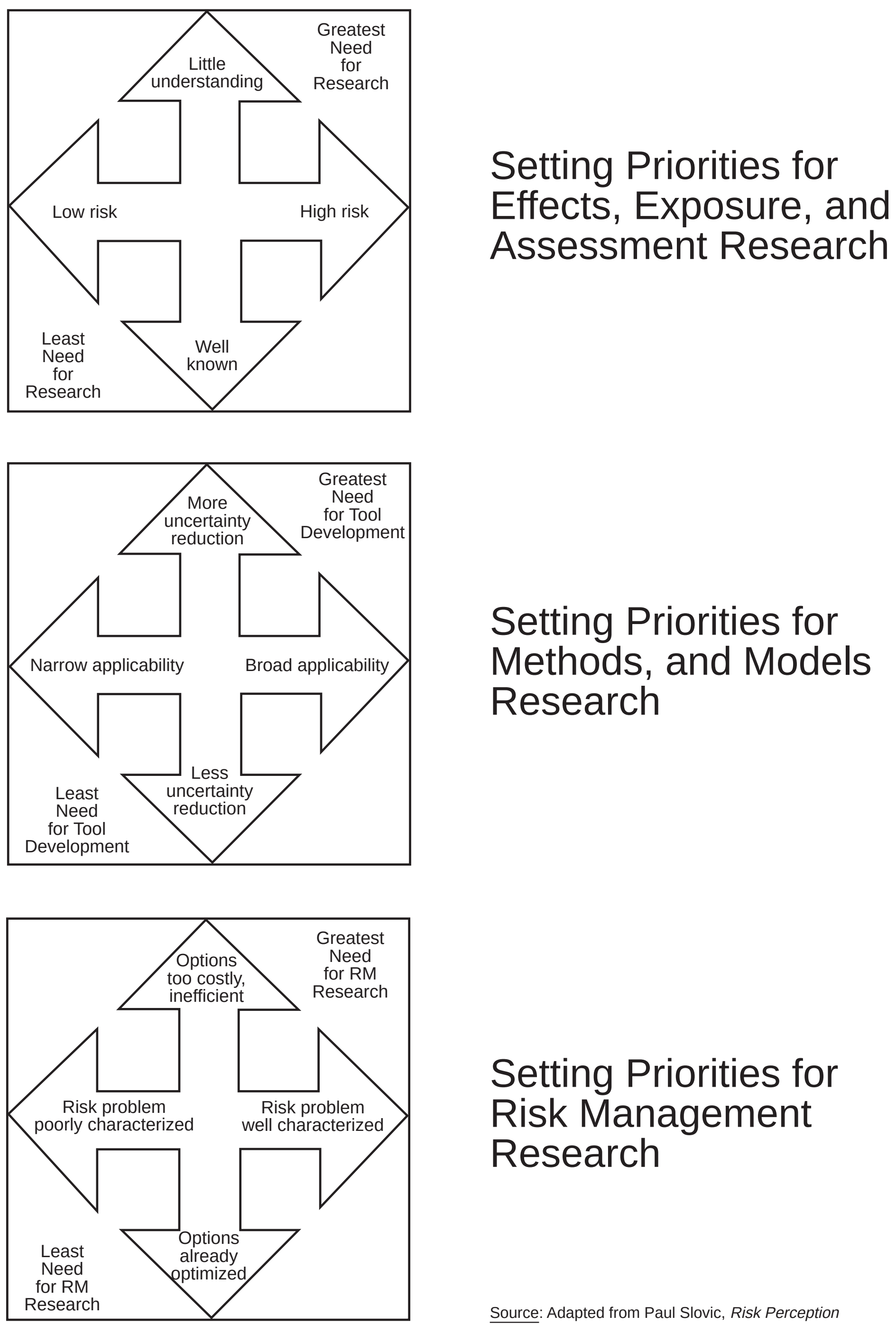
DOE has also been directed by Congress to establish a program in basic environmental research through grants and DOE's laboratories. The DOE Office of Energy Research conducts additional environmentally related basic science research in a variety of areas.

Many important waste sites have nuclear, mixed nuclear and hazardous, and other defense related wastes, such as conventional and chemical munitions. DOE and DOD have established research programs to address these specific needs. Coordination and collaboration with these research programs will continue to be pursued by ORD.

By using a variety of approaches, ORD will strive to leverage resources to meet identified needs and priorities while remaining in the forefront of scientific research in waste-related disciplines. This step will be revisited to consider how to best meet unfunded customer priorities when appropriate.

2.2.5 Prioritize Internal ORD Research Activities for Resource Allocation

Table 2-4 presents the remaining research activities addressed by the Waste Research Strategy and are research activities that ORD should conduct if funding exists. This table shows the "Science Plus" ranking of these waste research activities *across* the entire Waste Research Program. This is a consensus ranking arrived at in discussions amongst ORD, OSWER and Regional representatives, and serves as guidance for ORD funding decisions through FY00.



Source: Adapted from Paul Slovic, *Risk Perception*

Figure 2-3. Setting research priorities.

Table 2-3. Research activities ranked within each research topic area.

Research Topic Areas (in Priority Order)	RESEARCH ACTIVITIES BY RISK PARADIGM CATEGORIES					
	Risk Assessment			*Risk Management*		
	Exposure Assessment	Hazard Assessment	Risk Characterization	Remediation & Restoration	Control	Monitoring
Contaminated Sites - Ground Water	- Environmental Fate and Transport Modeling (4)* - GW Exposure Factors / Pathways (9)	- Mixtures Toxicology (12) - Ecosystem Effects (13) - Ecological Risk Assessment Methods (14) - Human Dose-Response Models for Mixtures (2)		- Natural Attenuation (1) - Abiotic Treatment of GW (5) - Biotreatment of GW (7) - Containment of GW (8) - Demonstration Verification of Innovative Remediation Technologies (10)		- Subsurface Characterization (3) - Field and Screening Analytical Methods for GW (6) - Demonstration Verification of Field Monitoring Technologies (10)
Contaminated Sites - Soils / Vadose Zone	- Estimating Human Exposure & Delivered Dose (1) - Estimating Soil Intake and Dose - Wildlife Species (2)	- Screening Tests to Measure the Effectiveness of Treatment (6) - Mixtures Toxicology (12)		- Biotreatment of Soils (2) - Containment of Soils (6) - Demonstration Verification of Innovative Remediation Technologies (9) - Abiotic Treatment of Soils (11) - Oil Spills (13)		- Field Sampling Methods (4) - Field and Screening Analytical Methods for Soils (5) - Sampling Design (8) - Demonstration / Verification of Field Monitoring Technologies (9)
Emissions from Waste Combustion Facilities	- Indirect Exposure Characterization Modeling (1) - Indirect Pathway Risk Assessment Methods (3)	- Movement of Bioaccumulative Chemicals in Food Webs (6) - Dose-Response of Key Contaminants (5)			- Emissions Prevention and Control (1)	- Continuous Emissions Monitoring (CEMs) Methods (4)
Active Waste Management Facilities	- Multimedia, Multi-pathway Exposure Modeling (1) - Environmental Fate and Transport, Physical Estimation (3)	- Chemical Toxicity Testing for Human and Ecological Endpoints (6) - Developing Provisional Toxicity Values for Contaminants (2)			- Waste Management (5)	- Waste Characterization and Sampling (4)

* Equals the ordinal rank of each research activity *within* each Research Topic Area based on the “Science Plus” ranking factors.

Table 2-4. Selected ORD waste research activities ranked across all research topic areas.

Research Topic Areas (in Priority Order)	RESEARCH ACTIVITIES BY RISK PARADIGM CATEGORIES					
	Risk Assessment			*Risk Management*		
	Exposure Assessment	Hazard Assessment	Risk Characterization	Remediation & Restoration	Control	Monitoring
Contaminated Sites - Ground Water	- Environmental Fate and Transport Modeling (7)* - GW Exposure Factors / Pathways (21)	- Mixtures Toxicology (26) - Ecological Risk Assessment Methods (38) - Human Dose-Response Models for Mixtures (3)		- Natural Attenuation (2) - Abiotic Treatment of GW (9) - Biotreatment of GW (16) - Containment of GW (17) - Demonstration Verification of Innovative Remediation Technologies (27)		- Subsurface Characterization (6) - Field and Screening Analytical Methods for GW (15) - Demonstration Verification of Field Monitoring Technologies (27)
Contaminated Sites - Soils / Vadose Zone	- Estimating Human Exposure & Delivered Dose (1) - Estimating Soil Intake and Dose - Wildlife Species (3)	- Ecological Screening Tests to Measure the Effectiveness of Treatment (18) - Mixtures Toxicology (34)		- Biotreatment of Soils (3) - Containment of Soils (18) - Demonstration Verification of Innovative Remediation Technologies (27) - Abiotic Treatment of Soils (31) - Oil Spills (36)		- Field Sampling Methods (8) - Field and Screening Analytical Methods for Soils (9) - Sampling Design (22) - Demonstration / Verification of Field Monitoring Technologies (27)
Emissions from Waste Combustion Facilities	- Indirect Exposure Characterization Modeling (13) - Indirect Pathway Risk Assessment Methods (11)	- Movement of Bioaccumulative Chemicals in Food Webs (33) - Dose-Response of Key Contaminants (24)			- Emissions Prevention and Control (12)	- Continuous Emissions Monitoring (CEMs) Methods (23)
Active Waste Management Facilities	- Multimedia, Multi-pathway Exposure Modeling (14) - Environmental Fate and Transport; Physical Estimation (25)	- Developing Provisional Toxicity Values for Contaminants (18)			- Waste Management (36)	- Waste Characterization and Sampling (32)

* Equals the ordinal rank of each research activity *across* the entire Waste Research Program based on the “Science Plus” ranking factors.

2.3 Ranking Research Activities within Research Topic Areas

The following sections briefly describe each of the RTAs, the scientific and technical uncertainties associated with them, and the rationale for the relative rankings of the research activities within each topic area.

2.3.1 Ranking Research on Contaminated Sites

2.3.1.1 Ground Water

Ground water has been contaminated by a large number of releases to the environment. In 1994, the National Research Council (NRC) estimated that the number of hazardous waste sites that are likely to have ground water contamination ranges from 300,000 to 400,000. The majority of this contamination is caused by leaking USTs, but a recent OSWER white paper indicates that up to 40,000 sites are potential candidates for the federal Superfund program and historically about 80 percent of Superfund sites have ground water contamination. The NRC assessment includes estimates of ground water contamination at RCRA facilities (1,500-5,000 sites), federal facilities (10,000-12,000 management units) and 20,000-40,000 state sites.

In the past, concerns about contaminated ground water have been associated predominantly with its risks to human health. Three hundred and fifty thousand people have been provided with alternative sources of drinking water at Superfund sites alone, and as the percentage of the Nation's population that relies on ground water expands past 50 percent, the number of people at potential risk will increase. Concern is growing about the extent to which ground water is impacting ecosystems, particularly through ground water transfer of contaminants to sediments and to surface water, which can be significant in some watersheds during periods of low flow.

Due to the complex nature of the contaminants at many sites and the complex subsurface hydrogeology encountered at most sites, there are many uncertainties associated with the assessment and management of ground water contamination and the cost of these activities is high. These are summarized below.

For risk assessment, the major uncertainties are:
- transport and fate mechanisms, particularly in complex strata
- predicting human toxicity of complex mixtures
- predicting risk to ecosystems

For site characterization, major uncertainties are:
- delineating ground water contaminants, particularly non-aqueous phase liquids (NAPLs)
- speciation of contaminants, particularly metals
- sampling and detecting contaminants at low concentrations
- achieving quick, low-cost ground water and NAPL characterization

For remediation, major uncertainties are:
- achieving cleanup goals of NAPLs and contaminated ground water
- assessing and optimizing long-term effectiveness of *in situ* ground water treatment and containment techniques
- achieving rapid, low cost cleanup

To address these uncertainties and associated high-priority research needs, 14 contaminated ground water research activities have been identified (Table 2-5). These activities were first ranked by a set of Science criteria and then a set of "Science Plus" criteria following a process described earlier in this chapter. These rankings are shown in Table 2-5 and the rationale for them is described in what follows.

Science Ranking

ORD has determined that the most significant problems to be addressed by contaminated ground water research are: 1) understanding the effectiveness and applicability of natural attenuation; and 2) the characterization and remediation NAPLs — a major source of ground water contamination. Assessment and remediation of ground water contaminated by dissolved pollutants is an important, but somewhat lower priority. These conclusions are based on several considerations. Natural attenuation (NA) has the potential for being a relatively inexpensive means of remediating sites. It appears, for example, that it is an effective technique for the remediation of fuel contamination under certain conditions. There is, however, very limited understanding on how to assess whether natural attenuation is working at a site. This includes locating the plume and determining the rate of contaminant disappearance. Proper site characterization and monitoring to show that NA is effective and protective may increase its costs substantially.

NAPL research is also a high priority. NAPLs are a persistent source of ground water contamination, and the resultant loss of the ground water resource and threat to human health and the environment may last for tens of decades. Without the removal or control of these major sources, treatment of contaminated ground water must go on indefinitely. Research results that will enable locating and chemically characterizing NAPLs will aid in the development of new, cost-effective risk management options, as will continued development of innovative NAPL extraction and destruction options.

Research on the assessment and remediation of contaminated ground water remains important. Techniques for cleaning up many sources of ground water contamination do not exist now and therefore improved, cost-effective plume remediation or containment techniques are needed to minimize risks from contaminated ground water. Similarly, improved techniques to characterize and assess the risks of ground water contamination are needed to set realistic cleanup goals and reduce cleanup and monitoring costs.

Research on ecosystem impacts of ground water was ranked low because health concerns are still of highest priority. Also, the impacts of ground water on ecosystems are limited, being mainly through contamination of riparian zones (e.g., sediments and surface waters); since during low flow periods ground water can contribute significantly to base stream flow. Also, since many contaminated sites lie beside or near surface waters, direct runoff from the sites is believed to be of greater importance than transport through ground water. However, many uncertainties about these ecosystems impacts exist, and therefore research in this area needs to be done if adequate funds exist.

Science Plus Ranking

As can be seen from Table 2-5, the Science Plus ranking of research activities differs from the Science ranking for research activities ranked in the lower half of the list, but the changes in ranking are not large. First, containment research was elevated in ranking because it is of high priority to OSWER. Second, the ranking of the two demonstration/verification activities was increased 1 to 3 places reflecting ORD's recognition that Congress has indicated that these activities are a priority through its explicit authorization of the SITE Program, its mandate for 10 SITE demonstrations, and its guidance that SITE be fully funded in FY97. Also, the SITE program recently received a very favorable SAB review. As a result of these three increases in ranking, mixtures toxicology human health effects research fell to a lower priority.

With the exception of these four changes, the ranking of research activities changed little from Science to Science Plus. This reflects the fact that with one exception, all the Science Plus ranking factors were equally applicable to all research activities in this topic area. These factors were: 1) high priority for research across the risk paradigm in the CENR report and by the Program Office, and 2) high Congressional priority (reflected by the annual Superfund appropriation of about $1.5 billion [22 percent of the Agency's budget]), high Administration priority (as reflected by the President's initiative to cleanup two-thirds of the Superfund sites by 2000, and by the tight, 8-10 year schedules for DOD and DOE site cleanups).

The **Natural Attenuation** research activity was ranked high for reasons described above. This particular research activity is focused on remediation issues and is supported by subsurface characterization and field analytical methods research.

Human Dose-Response Models for Mixtures was ranked high because there are currently very large uncertainties about the health risks from complex mixtures of ground-water contaminants. The presence of multiple contaminants may result in enhanced toxicity (synergism), decreased toxicity (antagonism), or a simple summation of the toxicities of the individual contaminants (additivity). Current practice is to generally assume additivity, which can result in either an under- or overestimation of the actual risk. Research in this area will use existing scientific toxicologic studies and mechanistic data to develop dose-response models and toxicity values for common mixtures of contaminants. **Mixtures Toxicology** was ranked lower because hazard identification was judged less urgent a need than developing dose-response models or factors. Existing studies of individual contaminants should be used first to develop dose-response models before initiating toxicologic studies of mixtures. Once dose-response models have been developed with the existing data base, then toxicologic studies would be initiated on actual mixtures.

The **Subsurface Characterization** research activity was ranked high because of the inherent complexity of the subsurface and the contribution of the research activity to resolving both NA and NAPL characterization problems.

Environmental Fate and Transport Modeling is a high priority because it is basic to our understanding of the various natural and contaminant-induced processes that occur in an aquifer. Ground water modeling allows us to understand how these various processes, along with remediation activities, impact contaminant fate and transport. Such an understanding is important scientifically, as well as to make sitespecific assessment and cleanup decisions.

Abiotic Treatment was ranked high because of its focus on NAPLs remediation. In addition, it involves studying *in situ* abiotic treatment options such as permeable reactive barriers, which are a more cost-effective option than pump-and-treat for major classes of contaminants in ground water.

Field and Screening Analytical Methods were ranked high because of the need for improved methods to characterize and monitor sites for natural attenuation, and quicker, less-expensive characterization and monitoring methods. This research would also lead to more thorough characterizations because more samples could be analyzed in the field and the results used immediate.

Biotreatment and **Containment** research activities were ranked lower because they deal primarily with the control and remediation of contaminated ground water, a lower priority than NA and NAPLs cleanup. Biotreatment remains important to consider along with abiotic treatment because the two are likely to complement each other in terms of the contaminants they can address. Also, biotreatment may have application to residuals from NAPLs extraction. Under the Science ranking, containment was ranked lower than biotreatment because ORD believes that remediation of contaminants is at least as important as containment in terms of risk management, and because pump-and-treat can be used as a containment technique at many sites. The ranking for containment was increased because OSWER feels that it is an option of equal importance to treatment with significant implementation uncertainties. Containment research is particularly important for minimizing NAPL transport, for confining plumes to allow NA to occur, and for determining the long-term effectiveness of containment systems.

Ground Water Exposures Factors / Pathways was ranked in the middle because current research has been successful in identifying and quantifying key exposure factors such as drinking-water intake rates for various activities. There are still significant uncertainties associated with estimates of contaminants from non-ingestion routes of exposure, such as showering and use of appliances.

The two research activities dealing with **Demonstration / Verification of Innovative Technologies** were moved up in the Science Plus ranking because of the high priority allotted to them by Congress. While these two research activities do not develop new technologies, they are an important ORD activity for contaminated ground water (and soils), because they allow ORD to evaluate technologies developed outside the Agency. These "independent" evaluations provide credible reports on the applicability, performance, and cost of these technologies to site managers and other decision makers. Evaluation of innovative ground water remediation technologies is particularly important, because there are no effective technologies currently

Table 2-5. Focus and ranking of research activities for contaminated sites - Ground Water.

Research Activity Title	Potential Research Focus	"Science" Ranking	"Science Plus" Ranking
Natural Attenuation (NA)	• Determine under what conditions NA is applicable. • Determine techniques for assessing site-specific applicability of NA.	1	1
Human Dose/Response Methods for Mixtures	• Develop biologically based toxicity models. • Develop expert systems for determining likelihood of synergism antagonism or additivity of response.	2	2
Subsurface Characterization	• Develop surface based, noninvasive methods to characterize the structure and contaminant distributions in the subsurface.	3	3
Environmental Fate and Transport Modeling	• Determine processes affecting contaminant fate of transport, particularly in heterogeneous environments. • Develop improved models for representing site-specific ground water fate and transport, and effects of remediation.	4	4
Abiotic Treatment	• Develop more cost-effective techniques for NAPL remediation. • Develop more cost-effective techniques for ground water remediation.	5	5
Field and Screening Analytical Methods	• Develop field portable and screening analytical methods for rapid analysis of ground water. • Develop analytical methods to determine the status of and to monitor the rates of natural attenuation in ground water.	6	6
Biotreatment	• Determine more cost-effective techniques for ground water remediation.	7	7
Containment	• Develop more cost-effective methods to contain NAPLs and contaminated ground water. • Develop methods for evaluating long-term effectiveness of containment systems.	10	8
Ground Water Exposure Factors/Pathways	• Determine contaminant intake rates from showering, bathing and use of household appliances (e.g., dishwashers). • Develop exposure models for vapors released indoors.	8	9
Demonstration/Verification of Innovative Ground Water Remediation Technologies	• Produce technically sound performance, cost and applicability data for full-scale innovative remediation technologies.	11	10
Demonstration/Verification of Field Monitoring Technologies	• Produce scientifically sound performance data for innovative ground water monitoring and characterization technologies.	13	10
Mixtures Toxicology	• Develop improved models of the synergistic/antagonistic effects of contaminant mixtures.	9	12
Ecosystem Effects	• Develop screening tests to determine the effects of contaminated ground water on ecosystems.	12	13
Ecosystem Risk Assessment Methods	• Develop methods to determine the flux of ground water contaminants into sensitive ecosystems such as wetlands. • Develop ecotoxicity transfer/dilution factors between ground water and surface water. • Develop ground water ecotoxicity criteria and screening levels.	14	14

available. Evaluation of innovative ground water contamination characterization techniques is also important to help fill gaps where there is a lack of adequate techniques and to improve cost-effectiveness.

Research on **Mixtures Toxicology** was ranked lower because the need to develop information on interactions between mixture constituents was judged less urgent than the need to develop dose-response models for mixtures using existing databases.

Ecosystems Effects and **Ecological Risk Assessment Methods** were ranked lowest despite uncertainties about the effects of ground water on ecosystems, because the impact is expected to be low compared to human health effects.

2.3.1.2 Soils/Vadose Zone

The complexity and heterogeneity of soil/vadose zone matrices present a large number of technical challenges to their assessment and remediation. There are numerous uncertainties associated with soil/vadose zone decisions and the cost of remediation is still high (remedial actions alone cost an average of $9 million per Superfund site in 1996). Local risks to humans and ecosystems, high costs and uncertainty in decision making are all reasons for supporting contaminated soil/vadose zone research.

Specific scientific uncertainties are associated with each step of the site evaluation and remediation process. In the risk assessment process, major uncertainties are:

- magnitude of effects on human health and the ecosystem
- contributions of indirect pathways to receptor exposure
- availability of adsorbed contaminants and treatment residuals to human and ecological receptors
- intake of contaminants across multiple exposure routes - ingestion, dermal exposure, and inhalation

In the site characterization process, major uncertainties are:

- sampling of contaminants to determine their location and magnitude
- quantitative analysis of selected compounds
- design of sitespecific sampling strategies
- physical characterization of soils and the vadose zone

In remediation, major uncertainties are:

- applicability of treatment techniques to different contaminants and soil matrices, particularly heterogeneous matrices
- cost of remediation techniques

To address these uncertainties and associated high-priority research needs, 13 research activities were identified (Table 2-6). These activities were first ranked by a set of Science criteria and then a set of Science Plus criteria following a process described earlier in this chapter.

Science Ranking

ORD determined that a combination of site characterization, risk assessment and remediation research is needed in this topic area to address important scientific and technical issues, help clarify the risks posed by contaminated sites to surrounding communities, and reduce the high costs of site remediation. There are improvements needed in site risk assessments to reduce uncertainties in the magnitude of human health effects, and there are limited tools to evaluate the risks that these sites pose to ecosystems. The high cost of site remediation (and the ineffectiveness of some available technologies) requires research on innovative technologies. Improved site characterization contributes to both risk assessment and risk management, helping to define risks more accurately and define what needs to be remediated.

Science Plus Ranking

The Science Plus ranking of research activities (Table 2-6) varies little from the Science ranking for contaminated soils/ vadose zone, except that the two research activities on demonstration/verification of innovative technologies are ranked higher in the Science Plus ranking. This reflects the fact that with this one exception, all the Science Plus ranking factors were equally applicable to all research activities in this topic area. These factors included: 1) high priority given research across the risk paradigm in the CENR strategic plan and by the Program Office; 2) high Congressional priority (as reflected by the annual Superfund appropriation of about $1.5 billion); and 3) high Administration priority (reflected by the President's initiative to cleanup two-thirds of the Superfund sites by 2000 and by the tight 8 -10 year schedules for DOD and DOE site cleanups).

The two demonstration/verification research activities were given a higher ranking under Science Plus because Congress has indicated the importance of such work by requiring that ORD conduct ten demonstrations per year as part of the SITE program.

The **Estimating Human Exposure and Delivered Dose** and **Biotreatment** research activities were ranked highest, in part because both address the availability of contaminants in soils to impact receptors, particularly humans. Currently, it is assumed that all or most of an agent found in soils is biologically available, but this assumption is probably inaccurate. Improved estimation of the fraction of contaminants that are biologically available to humans or ecosystems could significantly reduce the estimates of risks at contaminated sites and reduce the cost of remediation by raising the level of the cleanup standard. The Estimating Human Exposure research activity would develop better models and factors for making these estimates for individual contaminants in soil. Research would include developing models for dermal exposure, estimating soil intake rates for children and adults, and estimating bioavailability of contaminants. In the long term, the Biotreatment research activity would evaluate the effectiveness of different types of biotreatment processes in different soil media based on these models and factors.

The Estimating Human Exposure research activity was also ranked high because its goal is to reduce other uncertainties associated with risk characterization. These include increasing the certainty of multipathway analysis, developing statistical distributions for exposure factors, and addressing specific issues related to soil risk, such as intake rates for children and adults.

The Biotreatment research activity was also ranked high because it would address natural attenuation of contaminants in soils (and landfills). Natural attenuation in soils has the potential for being a relatively low-cost means of site remediation, if its selection is justified and its progress is monitored to insure that there are no significant environmental risks. In addition, the Biotreatment research activity develops enhanced biotreatment processes for soils, vadose zones and landfills. These all have the potential to significantly reduce remediation costs, particularly *in situ* processes.

Estimating Soil Intake and Dose by Wildlife Species was ranked in the upper half because ecological risks are becoming more significant as drivers of cleanup levels at many contaminated sites. In most cases, soils are believed to have a more significant ecological risk at contaminated sites than do contaminated ground waters, due to the greater variety of wildlife that can come in direct contact with contaminated soils or feed on species residing in these soils. There are numerous uncertainties about the extent to which soil contaminants impact ecosystems and therefore ecosystems may not be adequately protected.

Field Sampling Methods and **Field and Screening Analytical Methods** were both ranked near the top because: uncertainty associated with site characterization is often high, thereby leading to uncertain risk assessment or high remediation costs, and there are significant savings in time and money to be gained by conducting analyses in the field.

Ecological Screening Tests to Measure Effectiveness of Treatment was ranked near the middle because it deals only with bioavailability issues and therefore is a more narrowly focused research area than Estimating Human Exposure or Wildlife Species research.

The **Containment** research area was ranked in the middle because its use is increasing because of its relatively low cost, yet there are still uncertainties about the long- term effectiveness of these systems and the most effective ways to install them. Also, there is the potential to reduce costs further by utilizing new materials for containment.

The research activity **Sampling Design** was ranked in the middle because improved designs can have a significant impact on reducing costs of cleanup by more accurately identifying what volumes of soils need to be remediated and what and where the sources of the risks are.

The two research activities dealing with **Demonstration / Verification of Innovative Technologies** were moved up in the Science Plus ranking because of the high priority allotted to them by Congress. While these two research activities do not develop new technologies, they are an important ORD activity for contaminated soils (and ground water) because they allow ORD to evaluate processes developed outside the Agency and through these "independent" evaluations provide credible reports on the applicability, performance and cost of these processes to site managers and other decision makers.

The **Abiotic Treatment** research area was ranked below Containment, Biotreatment and Demonstration/Verification of Innovative Remediation Technologies because it has less potential to impact cleanup costs or achieve significantly lower remediation levels. There are, however, important areas where abiotic treatment, either alone or as part of a multifaceted management option, is needed for cost effective site clean up.

The two remaining research activities: **Mixtures Toxicology** and **Oil Spills** are of less importance than the other research activities. Oil spills was ranked relatively low because its primary impact is to ecological systems. Research on Mixtures Toxicology of soil contaminants was ranked lower due to the sequence in which activities should be conducted to maximize research yield. For example, knowledge of the bioavailability of soil contaminants assists in predictions of the toxicological impact of mixtures.

2.3.2 Ranking Research on Active Waste Management and Combustion Facilities

Research evaluated under this topic area is limited to supporting OSW's Hazardous Waste Identification Rule (HWIR), developing the treatment technologies for wastes and waste streams that are hard to treat, and to understanding hazardous waste combustion risks and risk management options.

2.3.2.1 Active Waste Management Facilities

The current regulatory approach to the management of hazardous wastes is extremely burdensome and costly to the U.S. economy. In addition, the regulations are overly conservative and not founded on risk. As a result, the Administration is proposing regulatory reforms to provide administrative and economic relief by developing a multimedia, multipathway risk-based approach that is expected to exclude many wastes and waste streams from regulatory control under Subtitle C of RCRA (Hazardous Waste Identification Rule [HWIR]). In addition, acceptable disposal of hazardous wastes is specified by Land Disposal Restriction (LDR) rules. As part of these rules, Best Demonstrated Available Treatment (BDAT) technologies are specified that must be used to treat the waste prior to disposal. BDAT technologies were identified for each hazardous waste stream in the late 1980s and early 1990s and were based on the most effective treatment technologies that were commercially available at the time. It was recognized that there were some hard-to-treat wastes for which available technologies were either not sufficiently effective, or were very expensive, and that ongoing efforts would be needed to upgrade the BDAT technologies for a limited number of hazardous waste streams.

Major uncertainties are associated with several elements of the risk paradigm. Of the 400 waste constituents that require the development of "exit levels" under the proposed HWIR, 220 are without health-based levels (even fewer for ecologically based levels). These values need to be determined or estimated. In addition, approximately 210 of the constituents are without adequate analytical methods (current methods cannot measure the constituents at the proposed exit levels). Current multimedia modeling is constructed on a "most critical pathway" basis rather than on a mass balance basis. Components of some of the models are probabilistic and well developed (e.g., ground water) while others are poorly developed and deterministic or not developed at all. There is no system to exchange information between existing or planned models and data bases. Existing toxicity and environmental fate data bases are out of date and need to be updated with existing literature and new data. Methodologies to conduct assessments on mixtures or to ac-

Table 2-6. Focus and ranking of research activities for contaminated sites - Soils / Vadose Zone.

Research Activity Title	Potential Research Focus	"Science" Ranking	"Science Plus" Ranking
Estimating Human Exposure and Delivered Dose	• Estimate soil intake rates for children and adults. • Evaluate the bioavailability of contaminants in various soil matrices. • Develop and validate biokinetic dose-response models for lead and other heavy metals. • Derive dermal absorption factors for common soil contaminants. • Develop biotransfer and bioaccumulation factors for contaminants to facilitate estimates of exposure via the food chain. • Develop statistical distributions for exposure factors to facilitate use of probabalistic techniques to evaluate variability and uncertainty (e.g., Monte Carlo methods).	1	1
Biotreatment	• Determine under what conditions biotreatment processes can reach risk-based cleanup levels. • Develop less expensive cleanup processes for frequently found hard-to treat contaminants (e.g., TCE, PAHs, PCBs). • Develop inexpensive permanent cleanup options for landfills. • Determine when natural attenuation is an appropriate remediation option for soils and landfills.	1	2
Estimating Soil Intake and Dose for Wildlife Species	• Develop critical ecological exposure factors such as: species-specific soil intake rates, uptake factors from soils to plants to herbivores, species-specific dietary factors uptake factors from herbivores to carnivores, and data on migratory and range patterns. • Develop a wildlife contaminant exposure model that should be useful for constructing and evaluating site-specific scenarios. This model would allow calculations of intake via the food web and analyses of multiple exposure pathways and species. It would also include a probabalistic component to evaluate variability and uncertainty.	4	3
Field Sampling Methods	• Develop sampling methods that better preserve the integrity of contaminants in soil (e.g., volatile organic compounds). • Develop sampling approaches to better ensure that a sample is "representative" of the area surrounding tile sample location.	3	4
Field and Screening Analytical Methods	• Develop field-portable methods for rapid in situ determination of contaminants in soils. • Develop analytical methods to determine the status and rates of natural attenuation in soils.	4	5
Containment	• Develop methods for evaluating the long term effectiveness of containment systems. • Develop more cost-effective containment systems.	6	6
Ecological Screening Tests to Measure Effectiveness of Treatment	• Develop inexpensive methods to screen for significant risks from treatment residuals. • Develop inexpensive methods to determine cleanup goals.	6	6
Sampling Design	• Develop new statistical designs for sampling/characterizing contaminated soils at waste sites (e.g., multivariate, 3-D technologies).	8	8

Table 2-6. (Continued).

Research Activity Title	Potential Research Focus	"Science" Ranking	"Science Plus" Ranking
Demonstration/Verification of Innovative Remediation Techniques	• Produce technically sound performance, cost and applicability data for full-scale innovative remediation techniques.	12	9
Demonstration/Verification of Innovative Monitoring Technology	• Produce technically sound performance data for innovative soil monitoring and characterization technologies.	12	9
Abiotic Treatment	• Develop less expensive cleanup processes for hard-to-treat contaminants and matrices.	9	11
Mixtures Toxicology	• Develop improved models of the synergistic/antagonistic effects of common soil contaminant mixtures.	10	12
Oil Spills	• Develop more effective ways to remediate spills in an environmentally safe manner.	10	13

count for cumulative effects are nearly non-existent. Sound approaches for determining specific waste constituent compliance with proposed exit levels do not exist or, at best, have not been validated.

Uncertainties still exist in the treatment of some hazardous waste streams. There still remain a number of hard-to-treat waste streams, such as those containing mercury. As a result, it is not always possible to obtain the desired cleanup levels using current treatment technologies. In addition, there have been advances in existing, inexpensive treatment technologies (solidification/stabilization) that may make them more broadly applicable than previously, thus reducing costs of hazardous waste management.

Also, there is a need to reduce the volume of solid wastes requiring disposal, and this is not being done as quickly as it might, partially because of the uncertainty about the applicability of innovative recycling processes. This uncertainty may be reduced by improving the availability of technically sound information on innovative recycling techniques by having independent evaluations done on them cooperatively by government and private sectors.

To address these uncertainties and associated high priority research needs, six research activities have been identified (Table 2-7). These activities were first ranked by a set of Science criteria and then a set of Science Plus criteria following a process described earlier in this chapter.

Science Ranking

ORD has determined that a combination of environmental fate, exposure modeling, risk assessment, and waste management research is needed in this topic area. All four research areas are of high priority because each addresses important scientific and technical issues that can help determine or reduce the risks posed by active waste management facilities and hazardous waste generators.

Science Plus Ranking

As can be seen from Table 2-7, the Science Plus ranking of research activities is identical to the Science ranking except that the activity, "Chemical Toxicity Testing for Human and Ecological Effects," moved to the bottom of the list. With this one exception, the Science Plus ranking factors had little impact. These factors included: 1) high-priority across the risk paradigm in the CENR Strategic Plan and by the Program Office (OSW), 2) HWIR as a high-priority effort under the Administrations regulatory reform efforts, 3) the identification of waste research as "an area of high importance" in the ORD Strategic Plan, and 4) SAB and ORD recommendations for research resulting from their review of OSW's proposed HWIR. ORD considers the "Chemical Toxicity Testing for Human and Ecological Effects" research need to be of lower priority since it is essentially routine testing and is expensive.

The remainder of this section describes the rationale for the Science Plus relative ranking of the six research areas. This ranking reflects the application of science and other factors to determine the relative importance of each research activity.

The first four research areas (**Multimedia, Multipathway Exposure Modeling; Environmental Fate and Transport, Physical Estimation; Developing Provisional Toxicity Values for Contaminants;** and **Waste Characterization and Sampling**) are all responsive to the research needs identified by recent ORD and SAB reviews of the proposed HWIR. Research in all four areas is needed if a scientifically sound HWIR approach is to be developed.

Current exposure and risk models lack the ability to produce true multimedia, multipathway analyses. Major improvements are needed to ensure various models are compatible from the perspectives of computational, pathway, environmental scale, time scale, error propagation, and mass conservation/balance. Significant uncertainty still remains in the fate, transformation, and transport of many of the waste contaminants regulated under RCRA. These uncertainties include metal and organic compound speciation and the effects and rates of reductive and biological fate processes.

Until test-based toxicity values become available, provisional values will have to be estimated from the literature, from structure activity relationships, or from physical/chemical properties of the constituent. Much uncertainty remains in these current estimation methods, especially related to mixtures, bioavailability, and pharmacokinetics. As is the case for toxicity values, analytical methods are inadequate (as a result of poor sensitivity or specificity) or nonexistent for 210 of the 400 constituents. For wastes and waste constituents to "exit" regulatory control under RCRA, they must be present at concentrations *less than* the proposed "exit level" values developed through the multimedia, multipathway risk assessment approach proposed in HWIR. Great uncertainty exists, however, in how this is determined. OSWER has estimated that hundreds of millions of dollars per year can be saved as a result of this regulatory approach, but the research is needed to ensure the science is available to support a creditable HWIR (OSW, 1995c).

The **Waste Management** research area ranks fifth out of six areas. It is relatively less- important since it is a much more mature research area for ORD and significant resources have been committed to this area in the past. Most RCRA wastes and waste streams have established BDATs. However, there are still a number of "hard to treat" wastes where research could provide new or less-expensive technological solutions.

Chemical Toxicity Testing for Human and Ecological Endpoints ranks last because it is the routine application of standard toxicity testing protocols and is very expensive, thus, not a suitable use of limited research resources.

2.3.2.2 Emissions from Waste Combustion Facilities

There are 307 municipal waste combustion facilities with a current capacity of 104,000 tons per day. About 30 million people in 35 states and 900 communities are served by municipal waste combustion facilities. This accounts for approximately 16 percent of the waste generated annually. These facilities are known to emit toxic contaminants such as dioxin, furans, cadmium, lead, and mercury. In addition to large municipal waste combustion facilities, there are thousands of small incinerators such as those used to dispose of medical wastes. Recent studies indicate that medical waste incinerators are a major source of mercury emissions. There are also over 300 facilities burning hazardous wastes. These facilities include waste combustors (e.g., incinerators, cement kilns), industrial boilers and thermal desorption units. All of these units are burning complex mixtures of toxic contaminants, often in high concentrations, and therefore can contribute significant emissions on a site-specific basis if improperly designed or operated. Public acceptance of waste combustion and thermal treatment as a viable disposal technology is very low because of our inability to answer questions concerning the safety of this waste management option.

The risks associated with combustion facilities are potentially very high because (1) the number of combustion facilities is high, (2) the facilities have the potential to emit very toxic contaminants such as dioxin, furans, mercury, lead, and cadmium, (3) these emissions become dispersed over large geo-

Table 2-7. Focus and ranking of research activities for active waste management facilities.

Research Activity Title	Potential Research Focus	"Science" Ranking	"Science Plus" Ranking
Multimedia, Multipathway Exposure Modeling	• Develop true multimedia, multipathway exposure and risk models that support HWIR.	1	1
Developing Provisional Toxicity Values for Contaminants	• Review animal toxicologic studies, human epidemiologic studies, structure activity relationships, and then conduct dose-response assessments to derive Reference Doses, Reference Concentrations and/or cancer slope factors.	3	2
Environmental Fate and Transport; Physical Estimation	• Provide the science and environmental data needed to understand the fate, transport and transformation of RCRA constituents.	2	3
Waste Characterization and Sampling	• Develop the sampling methods, techniques and designs necessary to determine compliance with proposed RCRA exit level values. • Develop analytical methods with the necessary specificity and sensitivity to support exit level determination and compliance monitoring.	5	4
Waste Management	• Develop more cost-effective treatment options for hard-to-treat wastes. • Determine the applicability of innovative treatment options to hazardous wastes.	6	5
Chemical Toxicity Testing for Human and Ecological Endpoints	• Perform toxicity testing for high priority contaminants constituents of hazardous waste streams.	4	6

graphic areas that often have large populations or produce important food products (crops, animal, and dairy products), and (4) exposure occurs over several pathways and routes. These risks are also perceived by the public as very high as evidenced by community protests at facilities such as Waste Technologies Incorporated (WTI) in East Liverpool, Ohio, and at many Superfund sites such as New Bedford Harbor, Massachusetts, and Bloomington, Indiana.

The risks associated with combustion facilities are also highly uncertain and cut across the risk assessment paradigm. Areas of major uncertainty in exposure assessment include:

- What contaminants are being formed? What additional contaminants are formed as the emissions disperse and are transformed in the environment?
- What is the fate and transport of the contaminants? Where do they go and who might be exposed? What is the geographical scale of exposure? Current studies indicate that airborne contaminants are extremely mobile and can affect regional receptors.
- How much contamination are people and ecological receptors exposed to? Through what exposure pathways? How much contamination eventually makes its way into our food? And how much of the contamination found in our food is bioavailable to cause a toxic response in human receptors?
- How effective and accurate are current monitoring technologies?

Areas of major uncertainty in hazard assessment include:

- How toxic to humans are the contaminants that are being released? What doses of dioxin, furans, mercury, lead, cadmium and other contaminants are safe for human receptors?
- How harmful to ecological receptors are the contaminants that are being released? What amounts of dioxin, furans, mercury, lead, cadmium and other stressors are harmful?

Areas of major uncertainty in risk characterization include:

- Which contaminants being emitted present the greatest risk to human health and the environment and, thus, should be the focus of control efforts?
- What is the risk of cumulative continuous exposure? Combustion facilities are normally evaluated and regulated based on their individual emissions, exposure, and risk to surrounding receptors. The cumulative impact of continuous emissions from multiple combustion facilities and other sources of contaminants is not known.

The areas of greatest uncertainty in risk management are:

- How can emission levels of contaminants be reduced most cost-effectively?
- What are the combustion processes that lead to containment formation?
- Are process design/operation changes appropriate, or should add-on controls be used? What are the cheapest ways to minimize emissions from small combustors? How can the control of multiple emissions be most cost-effectively accomplished?

To address these uncertainties and associated high priority research needs, six research areas were identified: 1) exposure characterization and modeling; 2) continuous emission monitoring; 3) evaluation of the movement of metals in the food chain; 4) indirect pathway risk assessment methods; 5) dose-response assessments of key contaminants; and 6) emissions prevention and control (Table 2-8).

ORD first ranked these research areas relative to each other based on the potential for the research to either reduce risk; reduce uncertainties in risk estimation, site characterization or risk assessment; or reduce cleanup costs. The third column of Table 2-8 lists the research activities in order of decreasing priority based on this Science ranking. The fourth column Table 2-8 lists the ranking of research activities in terms of "Science Plus," reflecting revised priorities based on Congressional mandates, Program Office and Regional priorities, and other important considerations that are more of a managerial nature than solely scientific.

The Science Plus ranking of research activities is identical to the Science ranking for waste combustion facilities. This reflects the fact that all the Science Plus ranking factors were equally applicable to all research activities in this topic area. These factors included: 1) high priority for research across the risk paradigm in the CENR report; 2) high Administration priority as reflected by the Administrator's Combustion Strategy, which requires that all hazardous waste combustion facilities be evaluated for health and ecological impact using the indirect exposure methodology; 3) high priority by the Office of Solid Waste and Regional offices as evidenced by their commitment to establish with their own funds a Technical Support Center to evaluate indirect exposures; and 4) listing of waste research as "an area of high importance" in the ORD strategic plan.

Application of the Science Plus criteria did not impact any of the rankings *within* the Combustion Facility research topic. Applying the Science Plus criteria resulted only in some minor changes in the ordinals when combustion facility research areas were compared to the other three hazardous waste topic areas. The combustion research areas dropped to slightly lower ranks due to several factors. First, issues relating to combustion were judged by ORD as not as high a priority to the program offices as contaminated ground water or contaminated soil. Secondly, Congressionally authorized programs which received relatively lower science rankings (e.g., various SITE demonstration programs) were bumped upward in their science plus rankings.

The Waste Research Coordination Team (RCT) judged that the highest priority areas within the waste combustion facility topic area were emission prevention and control and exposure characterization/modeling. ***Emission Prevention and Control*** involves the characterization of waste combustion systems and their emissions along with the development and evaluation of techniques to prevent emissions formation or control their release. This area addresses incinerators and industrial systems burning wastes. It studies the reduction of emissions by system design and operation changes, as well as through the use of add-on controls. This area was judged as the highest priority because of the high potential for risk reduction and cost savings that could be achieved with reduced emissions from the waste combustion facilities. ***Indirect Exposure Characteriza-***

tion/Modeling involves developing improved fate, transport, and transformation models of contaminants that are emitted from waste combustion facilities. Current models lack the robustness and resolution to provide adequate fate and transport data needed to accurately estimate exposure and risk. Potential avenues of research include developing improved/validated complex terrain models for combustion sources, vapor-particle partitioning of semi-volatile organics (chlorinated dioxins and PAHs) under ambient conditions, air deposition of semivolatile organics (chlorinated dioxins, PCBs, higher molecular-weight chlorinated benzenes/phenols, PAHs, and high molecular weight phthalates), vapor transport to surfaces, wet and dry deposition, surface vapor uptake in plants and animals, mathematical models, parameter characterization, validation of models for dry gas deposition and air dispersion, and methods for particle size distribution for input to air dispersion models. This area was judged as the highest priority because of the very large uncertainties associated with the fate, transport, and transformation of emissions from waste combustion facilities.

Research on ***Indirect Pathway Risk Assessment Methods*** is needed to develop, validate, and refine a methodology that estimates exposures from combustion facilities via indirect (non-inhalation) exposure pathways. The indirect exposure methodology (IEM) is a multimedia and multi-pathway model that was developed for application to numerous emitted pollutants being released from stationary combustion sources. The methodology was developed to provide a set of procedures for the estimation of exposures resulting from emitted pollutants that have been transferred from the atmosphere to environmental media and biota. In addition, indirect exposures may result from uptake and transfer of an atmospheric pollutant through the terrestrial or aquatic food. Tasks in this research area include refining and validating the algorithm, developing guidance manuals on how to properly select input parameters, and developing an expert system. Research in this area is a high priority because recent risk assessments of waste combustion facilities indicate that the greatest risks appear to be those caused by these indirect exposure pathways. Typically, the risks resulting from indirect exposure pathways are an order of magnitude higher than those from the direct inhalation of emissions.

Conducting **Dose-Response Assessments of Key Contaminants Released** is also a high priority. The purpose of this research area is to develop updated dose-response risk assessments for contaminants that present the greatest risk from combustion facilities. As more scientific data become available in the form of animal toxicological studies, human epidemiological studies, and mechanistic toxicodynamic models, toxicity values (reference doses, reference concentrations, and cancer slope factors) will need to be updated to provide a more accurate estimate of risks. Because there is a linear relationship between the toxicity values and risk, any change in the toxicity value will translate into the same change in estimated risk. Currently, the “risk drivers” are mercury, dioxin, furans, cadmium, and lead. Because there are many ongoing epidemiologic and toxicologic studies of these contaminants, the Waste RCT judged that it was very important that the results from these emerging studies be evaluated and that current toxicity values be updated if necessary so that the risks from waste combustion facilities can be accurately estimated.

Research on ***Continuous Emissions Monitoring Methods*** is another important research area. Acceptance of incineration as a viable treatment option for hazardous waste has been hindered by an inability to know continuously how well the combustion units are performing and whether there are any unexpected emissions. Emphasis in this research area would be on toxic metals (lead, mercury, cadmium), dioxins, furans and other semi-volatile organics. Simple, inexpensive methods are especially needed for monitoring the thousands of small incinerators (e.g., medical waste incinerators) around the country. While this research area is very important in providing assurance to the public about the reliability of operations and uncertainties associated with incinerator emissions, ORD judged this area to be less critical than the previously described research areas, which should provide more reduction of uncertainty in our estimates of exposure and risk.

The purpose of research studying the ***Movement of Bioaccumulative Chemicals in Food Webs*** is to determine the ecological effects of emissions from combustion facilities by studying their uptake and transfer through terrestrial and aquatic food webs. Research would include the identification of indicator species and studies of species-specific exposure rates. Research would also include the study of contaminant bioavailability in combustor residues, including those from thermal treatment units. While this is an important area of research, ORD judged it to be a relatively lower priority because many of the principal contaminants of concern such as mercury and cadmium, have already been widely studied or are currently being studied by other programs. Any research would be targeted toward issues specific to waste combustion, such as bioavailability of specific forms of contaminants being emitted by waste combustion.

Table 2-8. Focus and ranking of research activities for emissions from waste combustion facilities.

Research Activity Title	Potential Research Focus	"Science" Ranking	"Science Plus" Ranking
Emission Prevention and Control	• Develop a better understanding of the combustion processes that lead to emissions formation. • Characterize toxic emissions from industrial hazardous waste combustion units. • Determine the most cost-effective means of controlling emissions from hazardous waste combustion units, especially industrial units and small incinerators.	1	1
Indirect Exposure Characterization/Modeling	• Determine the fate and transport of emission contaminants. • Develop models that identify and predict the formation of secondary contaminants from primary emissions.	1	1
Indirect Pathway Risk Assessment Methods	• Test and validate indirect exposure methodology (IEM) using site specific data. • Develop and validate contaminant biotransfer and uptake factors. • Develop guidance manuals and software program to apply IEM procedures.	3	3
Continuous Emissions Monitoring Methods	• Develop improved instruments that measure (on a "real time" basis) what contaminants are being released to the environment.	5	4
Dose-Response of Key Contaminants	• Complete the risk assessment of mercury. • Develop toxicity values (Reference Doses, Reference Concentration, Cancer Slope Factors) for critical contaminants.	4	5
Studies of the Movement of Bioaccumulative Chemicals in Food Webs	• Determine ecological effects of metal emissions. • Study the movement of mercury in aquatic environments. • Determine bioavailability of metals.	6	6

Chapter 3. Conclusions and Issues

Based on the analysis of research needs and ranking of research topics described in Chapter 2, ORD reached several conclusions and identified three issues that may require further attention.

3.1 Conclusions

1. There is a large and diverse set of waste research needs that span the spectrum of the risk paradigm. As a result, well integrated research programs are needed for each research topic area which have the goal of improving our assessment, characterization and risk management capabilities. Because there are insufficient resources available to meet all these research needs, the process of ranking research topics and activities is critical.

The large volumes of solid and hazardous wastes generated in the United States pose a number of environmental problems that EPA is responsible for minimizing. Given the variety of waste types and of past waste management practices, it is not surprising that there is also a variety of technical and scientific issues that need to be addressed. The CENR report identified broad risk assessment and risk management research needs for waste-related environmental problems, and OSWER and the Regions identified more- focused needs that support their regulatory programs.

2. *Four high-priority research topic areas and associated research activities were identified:*

- **Contaminated Sites - Ground Water.**

  The National Research Council (NRC) has estimated that 300,000 to 400,000 sites have contaminated ground water from USTs, and about 80 percent of the NPL sites have contaminated ground water. The subsurface is also the most complex and costly media to characterize, model, assess, and remediate, and there are still numerous scientific uncertainties associated with each of these topics. Congress appropriates approximately $1.2 billion annually to clean up the NPL sites and the Waste Research Program has demonstrated repeatedly the ability of its research to significantly reduce these costs.

  The focus of the research activities (Table 3-1) is on the issues of: improved risk assessment, characterization and remediation of non-aqueous phase liquids (NAPLs), the application and management of natural and accelerated process for subsurface remediation, and the demonstration and verification of innovative characterization and remediation technologies.

  The activities shown for contaminated sites - ground water are currently funded in the base research program except for mixture toxicology and containment of ground water.

- **Contaminated Sites - Soils/Vadose Zone.**

  The complexity and heterogeneity of soil/vadose zone matrices present many challenges to their characterization, assessment, and remediation. The cost of remediation is still high; remedial actions alone averaged approximately $9 million per site in 1996.

  The focus of research activities (Table 3-1) is on the issues of improved exposure and risk assessment of soils, the application and management of natural and accelerated process for remediation, and the demonstration and verification of innovative characterization and remediation technologies.

  The activities shown for contaminated sites - soils/ vadose zone are currently funded in the base research program except for mixture toxicology and estimating soil intake and dose for wildlife species.

- **Active Waste Management Facilities.**

  Currently, hazardous waste regulations are burdensome and costly to the U.S. economy. A proposal to provide administrative and economic relief by developing a multimedia, multipathway risk-based approach to exclude waste and waste streams has been made (proposed Hazardous Waste Identification Rule). However, for this rule to succeed, significant new science, models and data are required. Also, OSWER has identified a number of waste control/ treatment issues for waste and waste streams that are hard to treat or where current technological solutions are too costly or do not meet current treatment standards.

  The focus of the research activities proposed for this research topic area is on the science needs related to HWIR, especially in multimedia, multipathway modeling, and the development or estimation of toxicity values.

  The activities shown for active waste management facilities are currently funded in the base research program except for the development of provisional toxicity values and waste management.

- **Emission from Waste Combustion Facilities.**

  Waste combustion facilities are know to emit toxic contaminants such as dioxins, furans, cadmium, lead, and mercury. In addition to large municipal waste combustion facilities, there are thousands of small incinerators such as those used to dispose of medical waste which are suspected of being a major source of mercury emissions. Public acceptance of incineration as a viable disposal technology is very low because of our inability to answer questions related to emission sources, emissions monitoring, indirect exposure pathways, and economical control and monitoring of small incinerators.

Research in this topic area is on the control and monitoring of emissions, emissions fate process and transport modeling, and indirect exposure and risk assessment methods and models.

No research is funded currently in the base waste program.

3. *While there is much uncertainty, debate, and controversy about the health and ecological risks posed by waste sites, there is consensus that the economic impact of current waste management and cleanup practices is staggering. Within this context, waste research should be viewed as a relatively small and valuable investment to save future expenditures.*

Waste management and remediation are estimated to cost as high as $750 billion (Russell, *et al*., 1989). In contrast, ORD's research budget for FY97 was less than $50 million. This research, however, has yielded significant savings. For example, at a mining site in EPA Region 8, a $50,000 bioavailability study reduced cleanup costs from $8 million to $4 million (Weiss, 1997). Similarly, use of a phased characterization/sampling and analysis design at a dioxin contaminated soil site resulted in an overall savings of approximately $6.0 million (Ryti, *et al*., 1992, and Ryti, *et al*., 1993). A 1996 Analysis of 46 RODs showed that where innovative technologies of the type tested in the SITE program were used instead of conventional technologies, showed that an average savings of $30 million dollars per ROD was achieved (Gatchett, 1998). Clearly, there have been significant reductions in remediation costs resulting from research, and it is expected that future research will yield similar benefits.

4. *Because of the multi-disciplined nature of waste-related research, there are many organizations (across government, industry, and academia) actively involved in sponsoring research activities. In order to maximize efficiency of effort and avoid duplication, and to improve every organizations' understanding of waste research needs, special efforts need to be made to coordinate and leverage these research programs and activities.*

5. ORD's current research program emphasizes risk management research. There is a need to increase the relative amount of risk assessment research in this program.

About 80 percent of ORD's current waste research program is invested in risk management and monitoring, while only 20 percent is invested in risk assessment research. This is due to several factors. First, within ORD, the waste research program is the only place where characterization and remediation research specific to hazardous waste and Superfund sites is conducted. In contrast, a number of other ORD research programs (Human Health Protection, Ecological Research, etc.) have research efforts on topics related to generic risk assessment that benefit the waste programs. Additionally, CERCLA has mandated that ORD conduct 10 technology demonstrations per year as part of the SITE program. These activities utilize a significant portion of ORD's Superfund research resources. Finally, both NIEHS and ATSDR have Congressionally mandates to conduct basic research and develop toxicological profiles. While these efforts do not necessarily have a direct relationship to risk assessments at sites, they are helpful to the Superfund program.

There are several areas where risk assessment issues need to be addressed, either as part of the ORD waste research program, or by other research programs inside ORD or elsewhere. The research activities identified in Table 3-1 are those that should be conducted in whole or in part in the ORD waste research program. Both the risk assessment research activities (left three columns) and the risk management research activities (right three columns) address high-priority research needs. This research strategy provides guidance on deciding the relative emphasis that should be placed on risk management and assessment research from FY97 to FY00.

3.2 Issues

1. *Lack of Risk Characterization Research.* The CENR report identified risk characterization as a commonly overlooked, yet very important, research priority. ORD does not have any research activities under this component of the risk assessment paradigm. Should ORD conduct additional research in this area? If yes, should it be part of the Waste Research Strategy or is it more appropriate as part of another research plan such as the Research Strategy for Human Health Risk Assessment?

2. *Future Waste Strategy Development.* This waste strategy and its associated research plans present the first comprehensive waste research planning done by ORD. The planning will not stop with publication of this document. The authors plan to coordinate ORD discussions that will lead to a more integrated set of research activities both across ORD waste research and with other related ORD research programs, such as ecosystems protection. The research strategy itself will be revisited within two to three years to provide guidance beyond FY00.

3. Funding Strategies. The number and diversity of research needs far exceeds ORD's ability to meet them. ORD has identified a set of research activities through which it believes can make significant scientific contributions and that are responsive to many of the high priority needs. However, some of these activities are not currently funded in our base research program (FY97). These unfunded research activities are identified in **bold** in Table 3-1. Strategically, ORD will use four approaches to identify funds for these unfunded priorities. They are:

Annual Reallocation of Funds — Annually, for both the enacted and President's budgets, ORD will look for opportunities to reallocate funds to higher priority research from completed or lower priority research activities.

Research Appropriate for ORD's External Grants Program — Annually ORD will identify research needs that are appropriate for the external grants program. Generally, this will be in areas where fundamental advances to the science are needed. Unfunded high priority research activities will be emphasized.

Other Research Programs Where a Need May Be Met — ORD will seek to identify other ORD, Federal, or private sector research programs where high priority waste research needs may be met.

Additional Resources — Should additional resources become available, they will be allocated to high-priority unfunded or underfunded research activities.

Table 3-1. Research activities unfunded in the current base waste research program (**shown in bold**).

Research Topic Areas (in Priority Order)	RESEARCH ACTIVITIES BY RISK PARADIGM CATEGORIES					
	Risk Assessment			*Risk Management*		
	Exposure Assessment	Hazard Assessment	Risk Characterization	Remediation & Restoration	Control	Monitoring
Contaminated Sites - Ground Water	- Environmental Fate and Transport Modeling (7)* - GW Exposure Factors / Pathways (21)	- **Mixtures Toxicology (26)** - Ecological Risk Assessment Methods (38) - Human Dose-Response Models for Mixtures (3)		- Natural Attenuation (2) - Abiotic Treatment of GW (9) - Biotreatment of GW (16) **- Containment of GW (17)** - Demonstration Verification of Innovative Remediation Technologies (27)		- Subsurface Characterization (6) - Field and Screening Analytical Methods for GW (15) - Demonstration Verification of Field Monitoring Technologies (27)
Contaminated Sites - Soils / Vadose Zone	- Estimating Human Exposure & Delivered Dose (1) **- Estimating Soil Intake and Dose - Wildlife Species (3)**	- Ecological Screening Tests to Measure the Effectiveness of Treatment (18) **- Mixtures Toxicology (34)**		- Biotreatment of Soils (3) - Containment of Soils (18) - Demonstration Verification of Innovative Remediation Technologies (27) - Abiotic Treatment of Soils (31) - Oil Spills (36)		- Field Sampling Methods (8) - Field and Screening Analytical Methods for Soils (9) - Sampling Design (22) - Demonstration / Verification of Field Monitoring Technologies (27)
Emissions from Waste Combustion Facilities	**- Indirect Exposure Characterization Modeling (13)** **- Indirect Pathway Risk Assessment Methods (11)**	**- Movement of Bioaccumulative Chemicals in Food Webs (33)** **- Dose-Response of Key Contaminants (24)**			**- Emissions Prevention and Control (12)**	**- Continuous Emissions Monitoring (CEMS) Methods (23)**
Active Waste Management Facilities	- Multimedia, Multi-pathway Exposure Modeling (14) - Environmental Fate and Transport; Physical Estimation (25)	**- Developing Provisional Toxicity Values for Contaminants (18)**			**- Waste Management (36)**	- Waste Characterization and Sampling (32)

* Equals the ordinal rank of each research activity across the entire Waste Research Program based on the science plus ranking factors.

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Glossary of Terms

bioavailability: The availability of a chemical to an animal, plant or microorganism. It may be assayed by measurement of uptake, toxicity or biodegradability.

biomarker: A measurable indicator of exposure or effect in a biological receptor.

biodegradation: The biological conversion of an organic compound to products of simpler structure, often inorganic products.

bioremediation: The treatment of contaminants by biodegradation to reduce their concentration.

biosensor: An analytical device composed of a biological recognition element (enzyme, receptor, DNA, antibody, or microorganism) in intimate contact with a signal transducer (e.g., electrochemical, optical, thermal, or acoustic) that together relate the concentration or chemical property of an analyte to a measurable electronic signal.

cellular biology: The study of processes and interactions at the cellular level.

cone penetrometer: A hydraulically driven [geotechnical] tool for characterizing the arrangement of hydrogeologic materials.

dose-response assessment: The evaluation of the relationship between chemical exposure concentrations (dose) and the incidence of adverse effects in humans or other species (response).

exposure assessment: The determination of the conditions under which people could be exposed to contaminants and the doses that occur as a result of such exposure scenarios.

hazard assessment: The activities of hazard identification and dose-response assessment.

hazard identification: The determination of the identities and quantities of chemicals present as contaminants in the environment or manufactured for various uses, and the types of hazards they may pose to human health.

hydrofracturing: The injection of water into [contaminated] consolidated sediments to create fractures that increase the permeability of the sediments, thereby increasing the effectiveness of *in situ* treatment processes.

immunoaffinity: A separation technique using chromatography specific antibodies to extract the target analyte(s) from an environmental or biological matrix prior to detection by immunoassay or instrumental methods.

immunoassay: An analytical method based on the interaction of a specific antibody with its target analyte(s) used for detection and quantitation. Although based on biological reagents, immunoassays are physical assays.

immunochemical method: Analytical methods based on the reaction of a specific antibody with its target analyte(s) for extraction, cleanup, concentration, detection and quantitation.

immunochemistry: A scientific discipline bridging chemistry and biology, providing highly specific and precise quantitative methods for the study of environmental contaminants and human exposure assessment.

incineration: Thermal destruction of waste materials by oxidation.

innovative technology: Technology lacking sufficient published cost and performance data.

***in-situ* remediation:** Remediation processes that are processes applied "in place" in the ground, without excavation of the contaminated soil.

karst terrain: An irregular limestone region with sinks, underground streams and caverns.

kriging: A statistical procedure that geologist use to characterize subsurface; kriging maximizes the information obtained from a given number of samples.

mechanistic data: Information describing the process of how a toxic reaction occurs in an organism.

methodological research: Research conducted to develop improved procedures to evaluate risks.

mixed wastes: Wastes containing radio nuclides as well as other non-radioactive contaminants.

nonaqueous-phase liquid: A liquid consisting of organic compounds that are not completely miscible with water.

natural attenuation: Naturally occurring processes in the environment that act without human intervention to reduce the mass, toxicity, mobility, volume or concentration of contaminants.

pharmacokinetics: The field of study concerned with defining, through measurement or modeling, the absorption, distribution, metabolism, and the excretion of drugs or chemicals in a biological system as a function of time.

physiologically based: Pharmacokinetics based on measured pharmacokinetics (PBPK) physiological variables such as blood flows through organs.

phytoremediation: Set of processes that clean contaminated sites using plants.

risk assessment: The systematic, scientific characterization of potential adverse effects of human or ecological exposures to hazardous agents or activities.

risk characterization: The description of the nature of adverse effects that can be attributed to chemical contaminants, estimation of their likelihood in various exposed populations, and evaluation of the strength of the evidence and the uncertainty associated with the risks estimates.

risk management: The process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and to ecosystems.

risk paradigm: A theoretical framework describing the components of risk assessment and risk management processes, and the interconnection of these components. Also, termed the "risk assessment/risk management paradigm."

soil horizon: A layer of soil approximately parallel to the land surface that differs from adjacent layers in physical, chemical, and biological properties or characteristics such as color, structure, or texture.

soil vapor extraction: The use of vapor extraction wells with blowers or vacuum pumps to remove contaminants from soils and the subsurface.

solidification: Encapsulating the waste in a monolithic solid of high structural integrity.

solid waste management unit: A facility used for the treatment, storage or disposal of solid waste, including hazardous wastes.

stabilization: Converting contaminants into less soluble, mobile or toxic form.

stakeholders: Persons and organization who have an interest in an activity because they are involved in or affected by it.

thermal desorption: The use of elevated temperatures to remove contaminants from soils by causing them to vaporize.

toxicokinetic data: Information describing the adsorption distribution metabolism and elimination of a chemical in an organism.

vadose zone: The subsurface zone that extends between the ground surface and the ground water table.

vertical geomembrane curtain wall barrier: A vertical wall consisting of a thin, low permeability man-made material inserted in the ground to contain or divert ground water.

Appendix A. Summary of Research Needs

All the detailed research and support needs identified by the CENR, the Program Offices, Regional Offices, and the ORD are arrayed by risk paradigm in Tables A-1 through A-6 (one table for each element of the risk paradigm). These tables include data that identify the specific support or research need, the source of research need, and who/where the need should most appropriately be addressed. This set of needs is considered to be the “universe of needs” and the basis upon which ORD will determine what research is appropriate and for which it has the capability and capacity to conduct. The table attempts to identify “where” each identified research need should most appropriately be addressed. Those needs that are (or may be in the future) addressed in this plan are identified by **ORD Waste Research Plan** in bold. In many cases, relevant or related research is being conducted elsewhere that will partially or fully meet the stated research need. These other locations are also identified. If there is no entry for a given research needs, research is not currently planned nor has it been identified as being conducted elsewhere.

Table A-1. Summary of research needs - Hazard Assessment.

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Hazard Assessment	**IDENTIFICATION OF TOXIC ENDPOINTS**		
	- Greater emphasis on noncancer endpoints.	CENR OERR OSW	ORD Human Health Risk Assessment Research Plan
	- Improved understanding of the biological basis for toxicity and biologically-based extrapolation models between species.	CENR OERR OSW	**ORD Waste Research Plan**
	- Effects of short term exposure to contaminants at different ages.	CENR OERR OSW	ORD Human Health Risk Assessment Research Plan
	- Effects of dermal exposure on cancer and noncancer endpoints.	CENR OERR OSW	**ORD Waste Research Plan**
	- Effects of contaminants on ecological receptors.	CENR OERR OSW	Ecological Research Strategy
	DOSE-RESPONSE ANALYSES		
	- Biologically based toxicokinetic models.	CENR OERR OSW	**ORD Waste Research Plan** ORD Human Health Risk Assessment Research Plan
	- Variation in susceptibilities within and across species.	CENR OERR OSW	ORD Human Health Risk Assessment Research Plan
	- Improved understanding of biological mechanisms of action at the organ, cellular, and subcellar level.	CENR OERR OSW	**ORD Waste Research Plan** ORD Human Health Risk Assessment Research Plan
	- Understanding the relationship between exposure and dose, especially as it relates to bioavailability of contaminants.	CENR OERR OSW	**ORD Waste Research Plan**
	- Improved understanding of the effects of complex mixtures.	CENR OERR OSW	**ORD Waste Research Plan**
	- Development of predictive models of population dynamics for selected ecological or societal species of interest.	CENR OERR OSW	Ecological Research Strategy

Table A-2. Summary of waste research needs - Exposure Assessment.

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Exposure Assessment	**PHYSICAL ESTIMATION, TRANSFORMATION, AND FATE PROCESSES**		
	- Improve understanding of abiotic processes controlling transport, fate and bioavailability of chemicals in soil, natural waters, and sediment.	CENR	**ORD Waste Research Plan** ORD Multimedia Research Program
	- Improve understanding of bioaccumulation and metabolic processes controlling biodegradability of chemicals in microbial populations in soils, natural waters, and sediments.	CENR	**ORD Waste Research Plan** ORD Multimedia Research Program
	- Enhancement of the MINTEQA2 database. Validation/verification.	OSW	**ORD Waste Research Plan**
	- Addition of Redox database to MINTEQA2.	OSW	**ORD Waste Research Plan**
	- Evaluation of fate and transport parameters for hazardous constituents.	OSW	**ORD Waste Research Plan** ORD Multimedia Research Program ORD Air Toxic Research Program (in part)
	- Expert analysis of biodegradation rates for the subsurface environment.	OSW	**ORD Waste Research Plan**
	- Develop a working understanding of the microbiologic and abiotic processes contributing to the degradation of contaminants in the subsurface, especially as related to natural attenuation.	OERR	**ORD Waste Research Plan**
	- Determine the environmental fate of vegetable oils and animal fats in terrestrial and freshwater ecosystems.	OERR	
	EXPOSURE PATHWAYS AND FACTORS		
	- Improve methods for diagnosing route of exposure and exposure history.	CENR	ORD Human Health Risk Assessment Research Plan (in part)
	- Improve data on human activity patterns (e.g., food ingestion rates, time in various settings, etc.).	CENR	ORD Human Health Risk Assessment Research Plan (in part)
	- Better procedures / models for assessing dermal exposure, especially from soil, including matrix-specific and receptor-specific (e.g., race) properties.	CENR OERR	ORD Human Health Risk Assessment Research Plan (in part)
	- Bioaccumulation of metals, especially mercury.	OSW	ORD Human Health Risk Assessment Research Plan (in part)
	- Bioaccumulation of semi-volatile organics (chlorinated organics, PAHs, higher MW phthalates) and metals in terrestrial plants and animals, cycling of xenobiotics from terrestrial plants to detritus to soils to soil organisms.	OSW	ORD Human Health Risk Assessment Research Plan (in part)
	- Methods/models for determining the bioavailability of metals and organics from soils via the ingestion exposure route, plant to animal, animal to human (direct and indirect exposure).	OERR Regions	**ORD Waste Research Plan**
	- Guidance for determining residential exposure (dermal, inhalation) from NAPL contaminated ground water and soils (vinyl chloride, benzene, etc.).	OERR	ORD Human Health Risk Assessment Research Plan (in part)
	- Develop methods to collect exposure data from minorities, disadvantaged populations or other groups (children , women, etc.) likely to be disproportionately affected.	CENR OERR	ORD Human Health Risk Assessment Research Plan (in part)

Table A-2. (Continued).

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Exposure Assessment	**EXPOSURE PATHWAYS AND FACTORS (cont.)**		
	- Improved understanding of exposure to dose relationships.	CENR	ORD Human Health Risk Assessment Research Plan (in part) ORD Air Toxics Research Program (in part)
	MULTIMEDIA, MULTIPATHWAY EXPOSURE MODELING		
	- Evaluate existing/developing new fate, transport, and exposure assessment models for multimedia assessments.	CENR OSW	**ORD Waste Research Plan** ORD Multimedia Research Program
	- Better procedures to assess complex (e.g., multipathway/multichemical) exposure scenarios.	CENR OSW	**ORD Waste Research Plan** ORD Multimedia Research Program
	- Enhancement of OSW subsurface fate and transport models by incorporating fractured flow and heterogeneous porous media.	OSW	**ORD Waste Research Plan**
	- Validation and verification of fate and transport models in general.	OSW	**ORD Waste Research Plan** ORD Multimedia Research Program
	- DOE Spill Test Facility -- fundamental dispersion modeling research	CEPPO	
	- Research on large-scale gas releases and liquid spills under varying weather, density, terrain, and surface roughness conditions to validate and enhance exposure models.	CEPPO	ORD Air Toxics Research Program (in part)
	EXPOSURE MODELING TECHNICAL SUPPORT		
	- Fate, transport and modeling support for HWIR, OUST, OERR.	OSW OUST OERR	**ORD Waste Research Plan**
	EXPOSURE CHARACTERIZATION / MODELING - COMBUSTION / INCINERATION		
	- Correlation between combustion mercury emissions and methyl mercury levels in biomarkers.	Regions	**ORD Waste Research Plan** ORD Multimedia Research Program (South Florida Mercury Study)
	- Vapor-particle partitioning of semi-volatile organics (chlorinated dioxins and PAHs) under ambient conditions.	OSW	**ORD Waste Research Plan** ORD Human Risk Assessment Research Plan (in part) ORD Air Toxics Research Program (very little)
	- Air deposition of semi-volatile organics (chlorinated dioxins, PCBs, higher MW chlorinated benzene and phenols, PAHs, and higher MW phthalates).	OSW	**ORD Waste Research Plan** ORD Air Toxics Research Program (very little)
	- Vapor transport to surfaces - wet and dry deposition.	OSW	**ORD Waste Research Plan**
	- Surface vapor uptake - plants and soils.	OSW	**ORD Waste Research Plan**
	- Mathematical models, parameter characterization, and validation of models for dry gas deposition air dispersion.	OSW Regions	**ORD Waste Research Plan** ORD Air Toxics Research Program (in part)

Table A-2. (Continued).

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Exposure Assessment	**EXPOSURE CHARACTERIZATION / MODELING - COMBUSTION / INCINERATION (cont.)**		
	- Methods for particle size distribution for input to air dispersion models.	Regions	**ORD Waste Research Plan** ORD Air Toxics Research Program (in part)
	INDIRECT PATHWAY RISK ASSESSMENT METHODS - COMBUSTION / INCINERATION		
	- Indirect eco and human exposure methodology for combustion sources (incineration/thermal desorbers).	OSW OERR	**ORD Waste Research Plan** ORD Air Toxics Research Program (in part)

Table A-3. Summary of waste research needs - Risk Characterization.

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Risk Characterization	**RISK INTEGRATION**		
	- Methods to integrate the elements of a risk assessment in complex cases.	CENR	ORD Human Risk Assessment Research Plan
	- Quantitative statistical methods to evaluate variability and uncertainty.	CENR	ORD Human Risk Assessment Research Plan
	- Methods to assess cumulative risk.	CENR	ORD Human Risk Assessment Research Plan
	- Methods to include cultural and behavioral aspects into risk analysis.	CENR	
	RISK COMMUNICATION		
	- Risk communication strategies that include community members	CENR	
	- Better statistical and communication tools to communicate risks to the public and risk managers.	CENR	

Table A-4. Summary of waste research needs - Control.

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Control	**WASTE COMBUSTION**		
	- Characterization of dioxin/furan emissions from boilers, especially boiler tubes and boilers of various types; and from halogen acid furnaces.	OSW	**ORD Waste Research Plan**
	- Full scale PIC testing to better understand formation dynamics; particularly post-combustion PICs.	OSW	**ORD Waste Research Plan (related bench studies)**
	- Determine good combustion practices (design and operation) which will minimize emissions of priority pollutants, especially for small combustors.	OSW	**ORD Waste Research Plan**
	- Develop control techniques for mercury emissions. Improved mercury speciation.	OSW	**ORD Waste Research Plan**
	- Characterize emissions of high priority semivolatiles and Hazardous Air Pollutants from Waste combustion and develop effective control techniques.	OSW	**ORD Waste Research Plan**
	- Identification of organic and PIC surrogates for non-dioxin organics.	OSW	**ORD Waste Research Plan**
	WASTE TECHNOLOGY		
	- Research the chemical dynamics and long term efficacy of emerging waste solidification and stabilization technologies.	OSW	**ORD Waste Research Plan**
	- Evaluate treatment alternatives for wastes that contain mercury, particularly in light of air emissions and elemental mercury.	OSW	**ORD Waste Research Plan**
	- Evaluate the cross media transfer of contaminants during treatment.	OSW	**(Part of ORD tech. devel. activities)**
	- Evaluation of ground water/surface water interactions.	OSW	**ORD Eco. Protection Plan**
	- Municipal Innovative Technology Evaluation (MITE) Program.	OSW	
	- Guidelines: Life Cycle Management Evaluation of Waste Management.	OSW	**P2 Research Plan**
	POLLUTION PREVENTION & RECYCLING		
	- Source Reduction/Recycling Options for High Priority Processes.	OSW	**P2 Research Plan**
	- Technologies to Reduce Barriers to Recycling.	OSW	**P2 Research Plan**
	- Source Reduction Opportunities for Combusted Wastes.	OSW	
	- Criteria to Delay MACT Implementation Dates.	OSW	
	- National P2 Roundtable RCRA Priorities Support.	OSW	**P2 Research Plan**

Table A-5. Summary of waste research needs - Remediation.

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Remediation	**GROUND WATER REMEDIATION**		
	- Conduct field evaluations of ground water remediation technologies to obtain data on performance, cost and environmental effects.	CENR	**ORD Waste Research Plan**
	- Develop, demonstrate and evaluate in situ technologies, such as bioremediation, to remediate subsurface plumes.	CENR OERR	**ORD Waste Research Plan**
	- Develop technologies to characterize, model monitor and remediate contaminated plumes in ground water, particularly DNAPLs.	CENR OSWER	**ORD Waste Research Plan**
	- Identify new or improved techniques for removing or treating subsurface DNAPLs.	Regions	**ORD Waste Research Plan**
	- Develop workable site characterization protocols for evaluating the potential for using natural attenuation to meet cleanup goals in the subsurface.	OSWER	**ORD Waste Research Plan**
	- Develop understanding of microbial and abiotic processes contributing to contaminant degradation in the subsurface.	OERR	**ORD Waste Research Plan**
	- Conduct research to better understand the process associated with reactive barrier effectiveness and develop improved barrier media.	OERR	**ORD Waste Research Plan**
	- Develop improved methods of remediating ground water using vegetation planted and grown in the contaminated areas.	OERR	**ORD Waste Research Plan**
	- Develop improved methods for monitoring and evaluating performance of barriers designed to control migration of contaminated ground water.	OERR	**ORD Waste Research Plan**
	- Conduct research to understand the fate and remediation options for MTBE in fuels.	OUST	**ORD Waste Research Plan**
	- Conduct research in natural attenuation of fuels in ground water.	OUST	**ORD Waste Research Plan**
	SOIL/VADOSE ZONE REMEDIATION		
	- Conduct field evaluations of contaminated soils remediation technologies to obtain data on performance, costs and environmental effects.	CENR	**ORD Waste Research Plan**
	- Develop, demonstrate, and evaluate in situ technologies, such as bioremediation, for remediation of contaminated soils.	CENR ORD	**ORD Waste Research Plan**
	- Evaluate the applicability of composting remedies to stabilization of metals in surface soils.	OERR	
	- Develop workable site characterization protocols for evaluating the potential for using natural attenuation to meet cleanup objectives in the subsurface.	OSWER	**ORD Waste Research Plan**

Table A-5. (Continued).

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Remediation	**SOIL/VADOSE ZONE REMEDIATION (cont.)**		
	- Conduct research on NA of fuels in soils and vadose zone.	OUST	**ORD Waste Research Plan**
	- Develop understanding of microbial and abiotic processes contributing to contaminant degradation in the subsurface.	OERR	**ORD Waste Research Plan**
	- Develop improved methods of remediating soil using vegetation planted and grown in the contaminated area.	OERR	**ORD Waste Research Plan**
	- Investigate the basic natural biological, chemical, and physical mechanisms that affect the toxicity or mobility of contaminants in soils to identify and optimize remediation processes.	ORD	**ORD Waste Research Plan**
	- Determine the long-term effectiveness and costs of containment systems, the proper means of monitoring them and ways to fix them effectively.	OERR	**ORD Waste Research Plan**
	- Evaluate treatment technologies for contaminated sediments.	Regions	**ORD Contaminated Sediments Work Plan**
	LANDFILLS		
	- Develop, demonstrate, and evaluate in situ technologies, such as bioremediation, for remediation of landfills.	CENR ORD	**ORD Waste Research Plan**
	- Evaluate the performance of waste containment systems at working landfills.	OERR	**ORD Waste Research Plan**
	OIL SPILLS		
	- Develop, evaluate, and demonstrate innovative technologies to remediate and restore environments impacted by oil spills or chemical releases	CENR	**ORD Waste Research Plan**
	- Evaluate the environmental impacts of oil spills remediation options.	OERR	
	REMEDIATION CLEAN UP GOALS		
	- Develop techniques to measure the health of ecosystems and the effectiveness of restoration efforts.	CENR	**ORD Waste Research Plan**
	- Develop techniques for determining risk-based cleanup goals for a variety of remediation technologies.	OERR Regions	**ORD Waste Research Plan**
	BETTER MANAGEMENT DECISIONS		
	- Develop new information management and quality assurance tools and procedures to improve the speed with which data are collected, tracked, interpreted and reviewed at sites.	CENR	
	- Provide site-specific technical support, including in-depth support that deals with complex remediation problems.	OSWER	**ORD Waste Research Plan**

Table A-5. (Continued).

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Remediation	**BETTER MANAGEMENT DECISIONS (cont.)**		
	- Provide support for the development of Presumptive Remedies (guidance to speedy remedy selections and promote technically sound, consistent selections).	OERR	**ORD Waste Research Plan**
	- Expand bioremediation field data base to include composting.	OERR	**ORD Waste Research Plan**
	- Direct research and development expertise towards solving site-specific cleanup problems.	OERR	**ORD Waste Research Plan (technical support)**
	- Provide site-specific technical assistance on the application of subsurface modeling at contaminated sites, especially to address cleanup technical impracticability and the applicability of natural attenuation.	OSWER	**ORD Waste Research Plan**
	- Develop methodologies for evaluating the outcomes, or benefits, of cleanup projects.	OERR	
	- Develop tools and provide guidance on how to estimate costs of remediation projects to support cleanup decisions and justify budget requests.	OERR	(to be determined)
	- Develop and implement ways to ensure that recent scientific/engineering advances can be rapidly and correctly implemented in remediation practice.	ORD	**ORD Waste Research Plan**
	- Develop means to keep remediation stakeholders informed about state-of-the-art solutions to the highest priority technical problems.	ORD	**ORD Waste Research Plan**
	- RCRA CA Tech Support - Remediation	OSW	**ORD Waste Research Plan**
	FEDERAL FACILITIES		
	- Conduct field evaluations of technologies to remediate radioactive wastes and mixed wastes in order to obtain data on performance, cost and environmental effects.	CENR	DOE
	- Develop a national federal test site program at federal facilities to support technology development and evaluation.	CENR	DOD, DOE
	- Develop, demonstrate, and evaluate innovative technologies for characterization, identification, and remediation of energetic materials (e.g., unexploded ordinances and chemical munitions).	CENR	DOD
	- Coordinate development of robotics waste separation and characterization technologies that are applicable to high-level waste, mixed wastes, landfills and contaminated soils, and ground water contaminated plumes.	CENR	DOE

Table A-6. Summary of waste research needs - Monitoring.

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Monitoring	**FIELD SAMPLING METHODS**		
	- Innovative site characterization (especially and related to VOCs, metals, and natural attenuation).	OERR	**ORD Waste Research Plan**
	FIELD AND SCREENING ANALYTICAL METHODS		
	- Speciation of arsenic and selenium.	OSW	**ORD Waste Research Plan**
	- Evaluation of pesticide screening by GC/AED.	OSW	**ORD Waste Research Plan**
	- Direct determination of PAHs by capillary electrophoresis with laser-induced fluorescence detection.	OSW	**ORD Waste Research Plan**
	- Lower analytical detection limits for bioaccumulative chemicals.	OERR	**ORD Waste Research Plan**
	- Develop a wider spectrum of immunoassay tools and methods for soil screening.	Regions	**ORD Waste Research Plan**
	- Improve data on contaminant levels and release rates from sites, especially field analytical methods.	CENR OERR	**ORD Waste Research Plan** ORD Drinking Water Research Program (in part) ORD Air Toxics Research Program (in part)
	- Improve TCLP, especially for oily wastes.	Regions	
	- Develop corrosivity and ignitability tests for solids.	Regions	
	CONTINUOUS EMISSION MONITORING (CEMs) METHODS		
	- Analytical methods for chloro- and bromo- dioxins and furans. Air, soils, waste residue, continuous emission monitors (CEMs) for combustion sources.	OSW	**ORD Waste Research Plan**
	- Develop guidance or improve analytical methods for better speciation of organics (PICs).	OSW	**ORD Waste Research Plan**
	- CEMs for mercury and mercury species.	OSW	**ORD Waste Research Plan**
	- Improved surrogates for emissions of PIC HAPs and associated CEMs.	OSW	**ORD Waste Research Plan**
	- Lower detection limits of VOST methods for PICs.	OSW	**ORD Waste Research Plan**
	- Improved discrimination of coeluting PIC peaks.	OSW	**ORD Waste Research Plan**
	- Inexpensive monitors for good combustion conditions for small units.	OAQPS	**ORD Waste Research Plan**
	- Improvement to the Total Organic Emissions Test (TOE).	Regions	**ORD Waste Research Plan**
	DEMONSTRATION & VERIFICATION OF FIELD MONITORING AND CHARACTERIZATION TECHNOLOGIES		
	- Demonstration of innovative monitoring and site characterization technologies.	OERR TIO	**ORD Waste Research Plan**

Table A-6. (Continued).

Risk Paradigm Element	Research Needs Sorted by Major Research Activities	Source of Research Need	Who/Where Will Need Be Addressed
Monitoring	**SPATIAL ANALYSIS AND OPTIMIZED SAMPLING DESIGNS**		
	- Innovative site characterization (especially as related to natural attenuation).	OSW OUST OERR	**ORD Waste Research Plan**
	SURFACE / SUBSURFACE CHARACTERIZATION TECHNOLOGY DEVELOPMENT AND EVALUATION		
	- Innovative site characterization (especially as related to natural attenuation).	OSW OUST OERR Regions	**ORD Waste Research Plan**
	- Develop innovative techniques for locating DNAPLs in the subsurface.	OERR	**ORD Waste Research Plan**
	- Develop methods for monitoring and evaluating the performance of barriers designed to control migration of contaminated groundwater, especially DNAPLs.	OERR	
	MONITORING AND CHARACTERIZATION TECHNICAL SUPPORT		
	- Technical support on sampling and analysis and CEMS for PICs, metals, and PM.	OSW	**ORD Waste Research Plan**
	- RCRA corrective action technical support.	OSW	**ORD Waste Research Plan**
	- Superfund site-specific monitoring and characterization (including remote sensing) technical support.	OERR Regions	**ORD Waste Research Plan**
	- Training courses: fate and transport of contaminants and DNAPLs.	Regions	

Appendix B. Related Research Programs

B.1 Related Research in the Office of Research and Development

B.1.1 Hazardous Substances Research Centers

The competitive Hazardous Waste Research Centers were created as a result of the CERCLA amendments of 1986 (P.L. 99-499). Section 311, directs EPA to " ... make grants to institutions of higher learning to establish and operate not fewer than five hazardous substance research centers in the United States. In carrying out this program the Administrator should seek to have established and operated 10 hazardous substances research centers in the United States." The legislation goes on to say responsibilities shall include at least research and training related to the manufacturing, use, transportation, disposal, and management of hazardous substances and publication and dissemination of the results of the research. The focus of each center is to parallel problems within the geographic regions of the Centers.

ORD currently is supporting five HSRCs through base resources or Congressional directive. The Centers draw financial support through EPA, other federal agencies, academia, states, local communities and the private sector. The following table identifies the centers, their focus and their participating members.

Table B-1. Hazardous Substances Research Centers.

Center Name	Center Focus	Consortium Members
Northeastern HSRC	Industrial Waste • Incineration/thermal treatment • Characterization and monitoring • *In situ* remediation • *Ex situ* treatment processes	MIT, New Jersey Inst. of Tech, Rutgers, Princeton, Stevens, Tufts, Univ. of Med and Dentistry of NJ.
Great Lakes and Mid-Atlantic HSRC	*In situ* Bioremediation • *In-situ* bioremediation technology • Surfactant introduction tech. • Bioventing	U. of Michigan, Howard U., Michigan State
Great Plains/Rocky Mountain HSRC	Contaminated Soils and Mining Wastes • Soil and water contaminated with heavy metals • Soils and groundwater contaminated by organic chemicals • Wood preservatives that contaminate water • Pesticides identified as haz. waste • Improved tech. and methods to characterize and analyze contaminated soils • Waste minimization and P2 methods and technology	Kansas State U., Haskell Indian Nations U., Lincoln U., Montana State U., South Dakota State, U. of Iowa, U. of Missouri, U. of Montana, U. of Nebraska, U. of Wyoming, U. of Northern Iowa, and Utah State U.
South and Southwest HSRC	Contaminated Sediments • *In-situ* chemical mobilization processes in bed and confined disposal facilities • *In-situ* remediation • *In-situ* detection	Louisiana State U., Georgia Inst of Tech. , Rice U.
Western HSRC	Groundwater Cleanup and Site Remediation • Chlorinated solvents • Halogenated aromatic compounds • Nonhaloginated aromatics including petroleum derivatives • Ordnance wastes • Heavy metals • Evaluation of factors affecting the transport and fate of chemicals in the environment • Design and management issues for site remediation	Stanford U., Oregon State U.

B.1.2 Minority Centers

Two minority centers are currently funded: Southern University at Baton Rouge and University of Texas - El Paso. Both Centers are funded from within the Waste Research Program.

B.1.3 Small Business Innovations Research and Exploratory Research Grants

Small Business Innovation Research is a Federal, Congressionally mandated program funded through a set-aside of 2.5 percent of extramural research funds appropriated within an agency. The program's primary focus is on cleanup, resulting in proof of concept and actual demonstration of individual entrepreneur's technologies, many of which have application to remediation. The most current topic areas being pursued are addressed in the following table: "SBIR FY 1997 Topic Areas."

ORD has for many years solicited for exploratory research beyond that covered by directed or focused STAR solicitations. It is the opinion of ORD that there are many outstanding investigator initiated ideas that could contribute and move the science forward, yet have no vehicle for funding. The Exploratory Grants program attempts to fill this void. Eligibility is for academic institutions and non-profits. Broad areas of solicitation tend to be in categories such as: environmental chemistry, environmental physics, engineering, and human health and ecological effects. Proposals are solicited for all media, including waste management, risk assessment and remediation.

B.1.4 Companion ORD Research Strategies

The Waste Research Strategy is one of 10 separate strategies that have recently been or are being developed by ORD. They are:

Table B-2. Minority Centers funded from within the Waste Research Program.

Center Name	Center Focus	Consortium Members
Center for Environmental Resources Management	• Problems that effect low-income individuals and groups • Minority residents of the Mexico border region • Strengthen the capability of Hispanics to enter environmental careers	U. of Texas at El Paso
Institute for Environmental Issues and Policy Assessment Center for Energy and Environmental Studies	• Pollution Prevention • Environmental Equity • Mississippi River Env. Strategy • Environmental Risk	Southern U. at Baton Rouge

Table B-3. Small Business Innovation Research (SBIR) topics for 1997.

SBIR FY 1997 Topic Areas
Drinking Water
Municipal and Industrial Wastewater Treatment and P2*
Wet Weather Flow Treatment and Pollution Control
Prevention and Control of Indoor Air Pollution
Prevention and Control of NOx, VOCs, SO2, and Toxic Air Emissions*
Treatment, Recycling, and Disposal of Solid Wastes, Hazardous Wastes and Sediments*
In situ Site Remediation of Organically Contaminated Soil, Sediments and Groundwater*
Treatment or Removal of Heavy Metals at Contaminated Sites*
Pollution Prevention*
Advance Monitoring and Analytical Technologies*

* Of probable interest to the waste plan and clients

- Drinking Water Disinfection/DBPs
- Particulate Matter
- Arsenic in Drinking Water
- Endocrine Disruptors
- EMAP
- Human Health Risk Assessment
- Ecosystems Protection
- Global Change
- Pollution Prevention

Components of a number of these strategies, particularly those on human health, ecosystems and pollution prevention, deal with issues related to waste risk assessment and risk management. Completed strategies and abstracts of those still in preparation may be found at the ORD web site: www.epa.gov/ORD/resplans.

B.1.5 Pollution Prevention Research

Since the early 1990s, ORD's pollution prevention research and development program has been transformed from an extramural effort that promoted pollution prevention through technical assistance and information transfer to an in-house effort devoted to scientific and technical research on pollution prevention tools, methodologies, technologies, and approaches. Resource allocations have been reduced and targeted at support that provides post-doctoral researchers, master's-degree assistants, technicians, and analytical services with which to build the in-house capabilities of ORD scientists and engineers. This shift has caused ORD to reevaluate its pollution prevention priorities and to focus on a smaller set of high priority activities where it can make a significant contribution based on its unique expertise and capabilities.

In preparing the Pollution Prevention Research Strategy, it was essential that the above reorientation be given full consideration, and that a research and development program in pollution prevention be targeted at and supportive of building and strengthening ORD's in-house capabilities. As a result, four long-term goals have been identified:

I. ORD will deliver broadly applicable tools and methodologies for pollution prevention and sustainability.

II. ORD will develop and transfer pollution prevention technologies and approaches.

III. ORD will verify selected pollution prevention technologies.

IV. ORD will conduct research to address economic, social, and behavioral research for pollution prevention.

Pollution prevention progress in the next ten years will not proceed as rapidly as in the past ten, but the results of that progress can be even more significant. The "next wave" of pollution prevention can provide economic and environmental benefits in a host of situations. Since these advances likely will represent more fundamental changes in individual lifestyle, industrial process design (e.g., clean technologies), consumer products (e.g., benign chemicals), and land use, future research and development must focus on quantum leaps instead of incremental improvements. ORD will only be able to sustain this future direction if it concentrates on longer-term research which will produce a new generation of tools and technologies that move pollution prevention beyond the obvious and less formidable opportunities of the past.

B.2 Related Research Sponsored by the Office of Solid Waste and Emergency Response

OSWER provides resources to ORD and non-ORD entities for research of particular emphasis for their programs. Funding to any single project may be one time only or may be part of a longer term commitment. In the paragraphs below, several research areas that have been funded and identified by OSWER are described.

Chemical Emergency Preparedness and Prevention Office (CEPPO)

Analysis of emergency gas release data: CEPPO is providing funds under the Clean Air Act through the National Oceanic and Atmospheric Administration (NOAA) to the Desert Research Institute (DRI) for analysis of emergency gas release data collected at the Nevada Test Facility. The original data were generated by research work funded by ORD under the Clean Air Act; however, funding was terminated in September 1995. The data are critical to industry and others to validate dispersion modeling approaches to support hazard and risk assessments for the prevention of catastrophic accidental releases.

Catastrophic accidental release: At the Wharton School of the University of Pennsylvania, CEPPO-funded research projects are in progress on issues associated with catastrophic accidental release risk assessment, risk management, risk decision-making and accident investigation.

Catastrophic release of propane gas: Under a cooperative agreement with CEPPO, the State of Delaware is developing a model risk management program and plan for propane, including the modeling and assessment of the consequences of catastrophic releases of propane gas.

Chemical accident prevention: Under a cooperative agreement with CEPPO, the National Institute for Chemical Studies is conducting outreach, training, and technical assistance in chemical accident prevention, addressing particularly small businesses and local communities, and focusing on Sections 112 (r) and 507 the Clean Air Act. They are also analyzing local state and Federal chemical accident investigation reports to highlight problem areas, trends and significant findings.

Office of Underground Storage Tanks (OUST)

Expedited Site Assessment Tools for Underground Storage Tank Sites: A Guide For Regulators, EPA 510-B-97-001 - OUST is developing a manual that will help state and federal underground storage tank (UST) regulators evaluate and promote expedited site assessments. The manual will cover five major UST site assessment issues: the expedited site assessment process, geophysical methods for UST site investigations; soil gas surveys; direct push technologies; and field analytical methods for petroleum hydrocarbons. The equipment and methods presented in the manual will be evaluated in terms of applicability, advantages, and limitations for petroleum UST sites. OUST anticipates the manual will be available in March 1997.

How to Effectively Recover Free Product At Leaking Underground Storage Tank Sites: A Guide For State Regulators, EPA 510-R-96-001, September 1996 - This manual assists regulators in determining when recovery of free product is necessary, whether an appropriate recovery method has been proposed, and whether the free product recovery plan provides a technically sound approach. (This manual was done in conjunction with NRMRL, but was published as an OUST document).

How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers, EPA 510-B-95-007, May 1995 - This manual has been proposed, and whether the corrective action plan provides a technically sound approach to achieve cleanup. It covers 10 technologies.

Office of Solid Waste (OSW)

Risk Assessment — Exposure scenarios for wastes in commerce - Hazardous wastes are increasingly being recycled and the products from these recycling operations are finding their way into commerce and use by the public. Consequently, these materials have a number of unique attributes that require special evaluation. In particular, this work is concerned with the long term stability of constituents in stabilized matrices, the bioavailability of constituents under different conditions, and the development of models for exposure pathways that are not typical of waste management scenarios. This work is being conducted by OSW and its contractors.

Monitoring — Continuous emission monitors - In cooperation with the Department of Energy, OSW is researching and evaluating the long-term ruggedness of CEMs for mercury and other organics. These monitors, while used in Europe, have not been installed extensively in the United States. This effort involves researching the long-term performance and stability of these state-of-the-art monitors.

Formation of products of incomplete combustion (PIC) - Field sampling efforts have been underway over the last several years to evaluate the nature and extent of organic hazardous constituents that form as a result of incomplete combustion. In cooperation with cement producers, OSW has conducted a series of field studies to assess PICs in cement kilns.

Accelerated microwave extraction - In conjunction with Environment Canada, OSW is developing a microwave extraction method for organic compounds. OSW is continuing to develop the method and will conduct a round-robin study in order to evaluate and improve the performance of this method.

Fate and Transport Model Development — Groundwater contaminant movement modeling - Although ORD makes significant contributions to this area, OSW, with its specialized contractors and other academic experts, conducts development work to improve EPA's Composite Model for Transformation Products. OSW is presently working to restructure the Monte Carlo framework in the model so that we can separate model uncertainty from data variability. In addition, in conjunction with several industries, academic experts and the ORD, OSW will be reevaluating available subsurface biodegradation data.

Multimedia and indirect fate and transport modeling - In close coordination with ORD, as outlined in the draft Multimedia Science Plan, OSW is taking the lead on a number of areas; examples include the development of additional human health and ecological endpoints for new chemicals, refinement of the waste management units which describe the source of contaminants, revisions to several submodels including the overland flow model, and additional evaluation of loss processes.

Environmental Benefits Analysis — Contingent valuation of groundwater - OSW is restarting an effort to evaluate the nonuse economic benefits of avoiding groundwater contamination. This effort, being conducted in conjunction with OSW's specialized contractors, will use the controversial method of contingent valuation. Prior SAB review and additional peer review input has led to a strategy that requires some experimental testing of responses to validate the valuation information that OSW us acquiring.

Office of Emergency and Remedial Response (OERR)

MARSSIM (ORIA - lead): MARSSIM is a 750- page guidance document that addresses issues related to the proposed rule, "EPA Radiation Site Cleanup Regulation," such as how to set background levels and risk/method/decision confidence levels.

MARLAP (ORIA-lead): MARLAP is a document concerning analytical methods, especially measurement issues related to the Radiation Site Cleanup proposed rule.

Fact Sheets for Ground water/Modeling (and future potential EPA/DOE/NRC Interagency Modeling Working Group) (ORIA-lead): Four reports promoting modeling of hazardous and radioactive waste sites were completed and published by ORIA. Four fact sheets were prepared summarizing the reports:

- Environmental Characteristics of EPA, NRC, and DOE Sites Contaminated with Radioactive Substances.
- Computer Models Used to Support Cleanup Decision-Making at Hazardous and Radioactive Wastes Sites.
- Environmental Pathways Models - Groundwater Modeling in Support of Remedial Decision Making at Sites Contaminated with Radioactive Material.
- A Technical Guide to Groundwater Model Selection at Sites Contaminated with Radioactive Substances.

Groundwater/Modeling Document Review (and future potential EPA/DOE/NRC Interagency Modeling Working Group) ORIA-lead): Two documents on modeling were prepared:

- An Evaluation of Three Representative Multimedia Models Used to Support Cleanup Decision-Making at Hazardous, Mixed and Radioactive Waste Sites.
- A Recommended Guide to Documenting Groundwater Modeling Results at Sites Contaminated with Radioactive Substances.

The Kd Model and Its Use in Containment Transport Modeling: A multi-Agency workgroup is developing a guidance document concerning the distribution coefficient for groundwater modeling at sites, including mixed waste sites.

Estimation of Water Flux in the Unsaturated Zone - A Survey of the Available Techniques: A multi-Agency workgroup to develop a guidance document for groundwater modeling at sites, including mixed waste sites.

International Containment Conference: Technical conference for complex waste sites, including mixed waste sites.

Decision Support System: ORIA and OERR are funding delivery of a probabilistic decision tool for all waste sites, including mixed wastes sites. Product developed in conjunction with Sandia National Laboratory.

Technology Innovation Office (TIO)

Ground-Water Remediation Technologies Analysis Center (GWRTAC) — The GWRTAC was established in 1995 through a cooperative agreement between TIO and the National Environmental Technology Applications Center (NETAC). NETAC's overall mission is to facilitate the development and use of new groundwater technologies through: improving understanding and deployment of innovative groundwater remediation technologies; supporting customer groups requiring access to this technology developers and users. Current activities include assembling information to be included in case study and vendor information databases, placing the databases on the Internet, preparing technology status reports, and responding to requests for information on groundwater technologies.

Remediation Technologies Development Forum (RTDF) - The RTDF was established by EPA in 1992 and now includes a consortium of partners from industry, government agencies, and academia. RTDF's overall mission is to foster public-private partnerships to advance the development of more permanent-cost-effective technologies for the remediation of hazardous wastes. The RTDF works to achieve this goal through: identifying priority remediation technology development needs; establishing and overseeing action teams to plan and implement collaborative research projects to address remediation problems; and addressing scientific, institutional, and regulatory barriers to the use of innovative treatment technologies.

Five Action Teams have been formed within the RTDF to address priority research areas: Lasagna Consortium, Bioremediation Consortium, Permeable Barriers Action Team, In-Place Inactivation and Natural Ecological Restoration (INERT) Soil-Metals Action Team, and Sediments Remediation Action Team. Participants in each team provide funding or in-kind support for specific research efforts of the team.

TIO provide funds for the staff and contractors needed to support the logistics of running the forum (e.g., organizing meetings and conference calls). The research support currently provided by EPA through its participation on the RTDF teams is provided by ORD.

B.3 Research Conducted/Sponsored by Other Agencies and Departments

Major waste research programs exist in other agencies and departments. An important consideration for ranking waste research to be performed by EPA/ORD is the extent to which a research issue is being addressed elsewhere. Depending upon the particular research need, a small, sharply focused ORD effort might have significant impact even if another agency has a large research program addressing an apparently similar research issue. In addition, ORD's position as part of the lead environmental regulatory agency puts it in a unique leadership role for the research programs of others. On the other hand, given the nature of the issue and the resources directed towards it by other agencies, ORD might more wisely focus its resources elsewhere.

The description of eight other government programs follows. Each gives a brief indication of the mission, magnitude, scientific direction and sharpness of focus of other Federal programs to determine the extent to which ORD efforts might be complementary, synergistic, duplicative, or relatively inconsequential. Where possible, an Internet address is provided as a pointer to more information about these other programs.

The Department of Energy (DOE)'s Office of Health and Environmental Research (OHER) operates an Environmental Remediation Research program, which is focused on developing an understanding of the fundamental physical, chemical, geological, and biological processes that must be marshaled for the development and advancement of new, effective, and efficient processes for the remediation and restoration of the nation's nuclear weapons production sites [http://www.er.doe.gov/production/oher/habir/cover.html]. A primary effort is a comprehensive research program in bioremediation that integrates the full range of fundamental scientific disciplines necessary to advance this emerging technology. DOE-OHER's natural and accelerated bioremediation research program is designed to promote the use of living organism to reduce or eliminate waste. The microbial genome research program is designed to provide genome sequence and mapping data on microorganisms of industrial importance and on those that live under extreme conditions. The environmental technology partnerships program is intended to encourage university, national laboratory, and industrial partnerships to address fundamental bioremediation and integrated assessment research that is oriented toward reducing waste production and energy consumption in manufacturing processes. The subsurface science program is designed to understand the physical, chemical, and biological processes controlling the fate of complex chemical mixtures released to terrestrial subsurface environments; and research in the deep terrestrial biosphere.

DOE's Office of Environmental Management (www.em.doe.gov) is responsible for environmental restoration, waste management, technology development, and facility transition and management. The Office of Science and Technology (OST) (em-50.em.doe.gov) has the responsibility for developing better, faster, cheaper, and safer technologies for meeting DOE's 30-year goal for environmental restoration and waste management, and for managing crosscutting activities. OST administers research in four areas:

- Tanks (http://em-50.em.doe.gov/BEST/FA/tanks/tanks.html)
- Subsurface Contaminants (Integration of Plumes and Landfills) (http://em-50.em.doe.gov/BEST/FA/scfa/scfa.html)
- Decontamination/Decommissioning (http://em-50.em.doe.gov/BEST/FA/DD.html)
- Mixed Waste (http://em-50.em.doe.gov/BEST/FA/mw/mixedwaste.html)

It also manages three crosscutting research programs:

- Characterization, Monitoring and Sensor Technology (CMST) (http://em-50.em.doe.gov/BEST/FA/CMST.html)
- Robotics (http://em-50.em.doe.gov/BEST/FA/robotics.html)
- Efficient Separations (http://em-50.em.doe.gov/BEST/FA/ES.html)

The Strategic Environmental Research and Development Program (SERDP) is a multi-agency program created in 1990 through Public Law 101-510, and funded through the DOD [http://www.wes.army.mil/serdp/home/html]. As such it responds to environmental requirements of the DOD and those that the DOD shares with the DOE, EPA, and other government agencies. The program seeks to identify, develop, demonstrate, and transition technology from six areas: cleanup, compliance, conservation, pollution prevention, energy conservation/renewable resources, and global environmental change. In FY96, SERDP was funded at about $58 million, of which 30 percent, or about $17 million, was for cleanup research.

SERDP cleanup area focuses on conducting R&D to achieve more efficient and effective environmental cleanup of soil, sediment, ground water, surface water and structures already contaminated by past practices with hazardous materials (including unexploded ordnance), radioactive (low-level or mixed wastes) and toxic substances. The principal focus of this area is more cost-effective cleanup/remediation techniques and technologies, monitoring and characterization methods and technologies, and assessment methods.

The National Institute of Environmental Health Sciences (NIEHS) manages a large basic research program directed towards Superfund issues [http://www.niehs.nih.gov/sbrp/home.htm]. The program is mandated in CERCLA (Section 209), which establishes a “basic university research and education program” in NIEHS, and further reinforced in SARA (Title III, Section 311), where the program “may include” the following: epidemiologic and ecologic studies, advanced techniques for detection, assessment and evaluation of effects on human health of hazardous substances; methods to assess the risks to human health presented by hazardous substances; and methods and technologies to detect hazardous substances in the environment and basic biological, chemical, and physical methods to reduce the amount and toxicity of hazardous substances.

NIEHS grants in this program are generally for a five-year period, so new Requests for Application (RFAs) are only developed once every five years or in the event significant new resources are appropriated in a particular fiscal year. Annual funding has been averaging about $35 million/year. Projects supported include analytical chemistry, biomarkers, bioremediation, combustion engineering, ecology, epidemiology, exposure assessment, fate and transport, human health effects, and non-biological remediation. The most recent RFA was issued in FY94.

The Agency for Toxic Substances and Disease Registry (ATSDR) (http://atsdr1.atsdr.cdc.gov:8080/atsdrhome.html) was created by CERCLA with broad mandates including: Superfund site public health assessments, health investigations, surveillance and registries, applied research, emergency response, health education, and toxicological database development. ATSDR is required to prepare toxicological profiles of agents found commonly at Superfund sites, including identifying data gaps and research needs. ATSDR is further directed to ensure the development of an applied research program to address data gaps identified in the toxicological profiles. In FY96, ATSDR directed approximately $16 million to addressing its “substance-specific mandates,” including identification of priority hazardous substances, development of toxicological profiles on those substances, and research to answer major unknown questions about health effects.

ATSDR applied research serves two major functions: (a) to respond to the public’s concern, has human exposure to hazardous substances occurred and resulted in adverse health effects; and (b) to provide EPA with critical health-based information so that cleanup decisions that are effective and protective of public health can be made. ATSDR’s in-house research capability resides primarily in the area of human studies in communities at and around waste sites. ATSDR supports the Association of Minority Health Professions Schools, as directed by the Congress, to fill some data gaps identified in its toxicological profiles. Other data gaps ATSDR hopes will be filled on an “volunteer” basis by industry, or by EPA (through TSCA and FIFRA authority), NIH and the National Toxicology Program (NTP).

The United States Geological Survey (USGS), as described in a recent National Research Council review (*Hazardous Materials in the Hydrologic Environment: the Role of Research by the U.S. Geological Survey*, National Academy Press, 1996) has a number of programs in which studies are conducted to aid in resolving problems related to the contamination of surface and ground waters by hazardous materials. The Toxic Substances Hydrology Program (http://wwwrvares.er.usgs.gov/nrp/proj.bib/wood.html) is one such program. Areas of research focus on the fate and transport of contaminants and bioremediation and natural attenuation of contaminants, especially for petroleum sources. USGS has worked with ORD researchers at some Superfund sites.

The Department of Defense’s Office of Environmental Security (DOD-OES) sponsors the Environmental Security

Technology Certification Program (ESTCP) (http://www.acq.osd.mil/ens/estcp/main.html). ESTCP's goal is to demonstrate and validate promising, innovative technologies that target DOD's most urgent environmental needs. These technologies provide a return on investment through cost savings and improved efficiency.

The current cost of remediation and compliance in DOD is significant. Innovative technology offers the opportunity to reduce costs and environmental risks. ESTCP's strategy is to select lab-proven technologies with broad DOD and market application. These projects are aggressively moved to the field for rigorous trials that document their cost, performance, and market potential.

ESTCP Demonstrations - Successful demonstration leads to acceptance of innovative technologies by DOD end-users and the regulatory community. To ensure that the demonstrated technologies have a real impact, ESTCP incorporates these players in the development and execution of each technology. ESTCP demonstrations —

- Address real DOD environmental needs.
- Significantly reduce costs and risks and expedite implementation.
- Document and validate the cost and performance of new technologies for DOD end-users and the regulatory community.

The Rapid Commercialization Initiative (RCI) (http://rci.gnet.org/) is a federal/state/private cooperative effort to expedite the application of new environmental technologies. The participating federal agencies include the Department of Commerce, Department of Defense, Department of Energy and the Environmental Protection Agency; participating states and state organizations include the State of California Environmental Protection Agency, Southern States Energy Board, and the Western Governors Association. The program makes use of cooperative demonstration projects to identify barriers to the acceptance and use of new technologies; once identified, these barriers will be removed, where possible. The program consists of 10 projects, each of which will be demonstrating a different environmental technology. The main goals of the program are to identify and reduce the barriers that impede market entry of new technologies. It is the opinion of many technology developers and users, environmental groups, prospective investors, and states, that environmental technologies face a set of unique barriers stretching from initial demonstration to final market entry that make commercialization specially difficult.

The Interstate Technology and Regulatory Cooperation Working Group (ITRC) (http://www.gnet.org/gnet/gov/stgov/itrcindex.htm) was established in December, 1994 by the Develop On-Site Innovative Technology Committee, referred to as the DOIT Coordinating Group of the Western Governors Association. The Mission of the ITRC is to facilitate cooperation among states in the common effort to test, demonstrate, evaluate, verify and deploy innovative environmental technology, particularly technology related to waste management, site characterization and site cleanup. Western states participating include Arizona, California, Colorado, Idaho, Kansas, Nebraska, Nevada, New Mexico, Oregon, South Dakota, Texas, Utah and Washington. Other states that have joined or have sent observers include Delaware, Florida, Illinois, Kentucky, Louisiana, Massachusetts, New Jersey, New York, Ohio, Pennsylvania, Tennessee, and Wisconsin, and the Southern States Energy Board has actively participated in the deliberations of the ITRC. In addition to the state members there are some representatives from stakeholder groups and tribal representation. Federal advisors have participated in ITRC meetings from a number of Agencies including EPA (Technology Innovation Office), DOD, DOE and some of the armed services organizations.

ITRC is organized into three task forces and technology specific task groups. Task forces have been established for Electronic Communication Development, Case Studies, and Protocols and Regulatory Requirements. The Protocols and Regulatory Requirements Task Force has established task groups to address specific technologies in the areas of *in situ* bioremediation, Low- Temperature Thermal Desorption, Plasma Hearth Technology, and Real-time Field Measurement (site characterization and penetrometer system).

Appendix C. Research Ranking Process

This appendix describes the process for identifying and ranking of research areas (RAs) by Science and Science Plus criteria (Section 2.2.3).

ORD members of the Waste Research Coordinating Team (RCT) representing ORD's laboratories and centers, the Office of Science Policy and the Office of Resource Management and Administration participated in a ranking process which consisted of the following steps:

1. Identify and rank the RAs within each of the four research topic area (RTAs) using Science criteria.
2. Rank the four RTAs using Science criteria.
3. Produces a single Science ranking for the whole waste program by merging and ranking all the research activities in the four RTAs.
4. Revise the waste program Science ranking based on Science Plus criteria.

Representatives from OSWER and EPA Regional Offices were involved in the Science Plus ranking (Step 4). All four steps are described in more detail below.

Step 1 - Ranking RAs Within Each RTA

The first step in the process was to produce a "menu" of potential research activities that could be conducted under each research topic area. Potential research activities were described for each area of ORD risk assessment paradigm (effects, exposure, risk assessment and risk management). In identifying these activities, members of the group described the type of research most needed to address the environmental problems in each RTA — they did not restrict themselves to activities currently being conducted. The RCT critiqued these proposed lists to insure that they were complete and that all listed RAs were important.

The group then rank ordered all the RAs within a given RTA, based on the criteria in Table 2-1. All applicable criteria were given equal weight. A multivoting procedure was used. Each member was given ten votes and allowed to use at most 4 on an RA. If only the highest RAs were ranked under this process, a second voting was conducted to rank the lower priority RAs. In cases where a distinction in priority could not be made, RAs were given the same ranking.

The result of Step 1 was the ranking of RAs within each of the RTAs, as shown in Table 2-3.

Step 2 - Science Ranking of RTAs

The team conducted a qualitative relative ranking of the four research topic areas to help with ranking of research activities across the waste program in Step 3. The criteria used for determining relative importance among the four research topic areas were:

- Magnitude of risk
- Cost of available risk management options
- Uncertainty of risk, exposure/measurements, and risk management.

All three criteria were nominally given equal weight in this qualitative ranking. The relative significance of each criterion was ranked high, medium or low.

Based on these qualitative comparisons of each of the four research topic areas, the team determined the relative rankings indicated in the left hand column of Table 2-4. (As indicated below, the two Contaminated Sites Research Topic Areas were ranked very close to each other). An explanation of the rationale for the rankings follows.

Contaminated Sites-Ground Water (GW) and Soils/Vadose Zone (S/VZ) were ranked close to each other in relative importance because there were a number of complex factors to consider which made distinguishing the relative importance of the two RTAs difficult. These factors included:

- The cost of characterization and cleanup is high for both;
- Both occur at most contaminated sites;
- Both have significant unknowns and uncertainties in site characterization;
- Both have significant uncertainties in risk assessment, but those for soils are greater due to multiple pathways of exposure, bioavailability, issues etc.;
- Both media are heterogeneous and complex and more difficult to access than air or surface water;
- The potential health impacts of GW is believed to be higher than for S/VZ, but the potential ecological impacts for S/VZ are higher.

Contaminated Sites - Ground Water was ranked somewhat higher than soils for
following reasons:

- Once ground water is contaminated it is usually more difficult to remediate than soils;
- Once ground water is contaminated the risks are more persistent and it is generally harder to characterize the contamination;
- There are currently few effective remediation techniques for contaminated ground water, while there are adequate (if expensive) techniques available for many more soil/vadose zone remediation problems;
- The potential of contaminated sites adversely affecting drinking water supplies is growing as US demand on ground water increases. On a site-specific basis, the potential health risks to humans is usually higher from ground water contamination than from soil contamination if the contaminated aquifer is used for drinking water.

There were also tradeoffs in the relative ranking of different ranking criteria between waste combustion facilities (WCFs) and contaminated sites. There are more contaminated sites, but the exposure from air emissions at WCFs usually covers a larger area than exposure from most contaminated sites. There are significant risk assessment uncertainties for both WCFs and contaminated sites (especially soils).

Taking these trade offs and similarities in account, research on emissions from WCFs was ranked below research on contaminated sites because a) there are far fewer WCF sites (<3,000), than numerous contaminated sites and therefore the national risk from incinerators is believed to be lower, and b) the cost of remediation is in the tens of billions of dollars, while that for combustion is believed to be only a few billion.

Research related to environmental problems arising from non-combustion, active waste management units (AWMFs) was ranked lowest for two reasons. First, the risks associated with these sites are estimated to be low after years of developing improved management and disposal techniques. Second, and for the same reasons, the costs of waste treatment is generally low and treatment is adequately effective for most hazardous and solid wastes. However, there are uncertainties in predicting health and ecological effects on these facilities. Hence, there is need for HWIR research in order to predict effects from these facilities on a national basis.

Step 3 - Science Ranking of All Wastes RAs

The objective of this step was obtain a single rank-ordered list of all 39 RAs within the waste program The 4 lists of Science-ranked RAs from Step 1 were "merged" taking into account the Science criteria (Table 2-1) and the results of Step 2. There was no change in ranking of RAs within an RTA relative to each other, but RAs from different RTAs were interspersed amongst each other on the resulting list.
Placement of a given RA on the list was determined by reaching consensus in the group. The result was the list of 39 rank-ordered RAs shown in Table C-1. In cases where a distinction in priority could not be made, both RAs were given the same ranking.

Step 4 - Science Plus Ranking of All Waste RAs

Following the ORD strategic planning process, the rank-ordered list of RAs from Step 3 was then reviewed and the ordering revised based on Science Plus criteria. This was intended to insure that ORD priorities reflect the views of outside stakeholders for ORDs research programs, such as Congress, the Administration, and EPA Program and Regional Offices. Science Plus factors which could increase the ranking of a RA were:

1. Congressional directive
2. Court directive
3. Administration priority
4. EPA Priority
5. EPA Program or Regional Office priority
6. Area of new ORD funding in FY98
7. CENR research priority

The whole Waste RCT, including representatives of OSWER and a Regional Office, participated in the Science Plus ranking process.

Carrying out the Science Plus ranking resulted in adjusting the placement of RAs relative to their place in the Science rank-order (Table C-1). This ranking process was done through consensus to the extent possible. When necessary, votes were taken with one vote given to ORD, OSWER and the Regions.

The Science Plus rank ordering of RAs is shown in Table 2-4 (minus several RAs, as discussed in Section 2.2.5).

Table C-1. Waste RCT ordinal science rankings (February 1997).

1.	Estimating Human Exposure and Delivered Dose (CS)
2.	Natural Attenuation (GW)
3.	Biotreatment (CS)
3.	Human Dose-Response Models for Mixtures (GW)
3.	Estimating Soil Intake and Dose-Wildlife Species (CS)
6.	Indirect Pathway Risk Assessment Methods (CF)
7.	Subsurface Characterization (GW)
8.	Emissions Prevention and Control (CF)
8.	Environmental Fate and Transport Modeling (GW)
10.	Indirect Exposure Characterization and Modeling (CF)
10.	Field Sampling Methods (CS)
12.	Abiotic Treatment (GW)
12.	Field and Screening Analytical Methods (CS)
12.	Multimedia, Multipathway Exposure Modeling (AF)
15.	Field and Screening Analytical Methods (GW)
16.	Biotreatment (GW)
16.	Containment (CS)
16.	Screen Tests to Measure the Effectiveness of Treatment (CS)
16.	Developing Provisional Toxicity Values for Contaminants (AF)
20.	Ground Water Exposure Factors and Pathways (GW)
20.	Sampling Design (CS)
20.	Dose-Response of Contaminants (CF)
20.	Physical Estimation of Environmental Fate and Transport (AF)
24.	Mixtures Toxicology (GW)
25.	Abiotic Treatment (CS)
26.	Containment (GW)
27.	Waste Characterization and Sampling (AF)
28.	Demonstration/Verification of Innovative Remediation Technologies (GW)
28.	Movement of Bioaccumulative Metals in the Food Web (CF)
30.	Continuous Emission Monitors (CF)
30	Ecosystems Effects (GW)
30.	Mixtures Toxicology (CS)
33.	Oil Spills (CS)
33.	Demonstration/Verification of Field Monitoring Technologies (GW)
33.	Waste Management (AF)
36	Demonstration/Verification of Field Monitoring Technologies (CS)
37.	Chemical Toxicity Testing (AF)
37.	Ecological Risk Assessment Methods (GW)
37.	Demonstration/Verification of Innovative Remediation Technologies (CS)

AF - active waste management facilities
CS - contaminated soils
CF - combustion facilities
GW - contaminated ground water

United States
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