

NCEA-I-0710  
Workshop Review Draft  
November 1999

## Mercury Research Strategy

### NOTICE

THIS DOCUMENT IS A PRELIMINARY DRAFT. It has not been formally released by the U.S. Environmental Protection Agency and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

Office of Research and Development  
U.S. Environmental Protection Agency  
Washington, DC 20460

## DISCLAIMER

This document is a draft for review purposes only and does not constitute U.S. Environmental Protection Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

1 **FOREWORD**

4 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  
7 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  
10 manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce  
environmental risks in the future.

13 The 1996 *Strategic Plan for the Office of Research and Development* sets forth ORD's vision, mission, and  
long-term research goals. As part of this strategic planning, 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  
16 strategies and plans that ORD has developed, or is developing. It helps in identifying the individual, high-priority  
topics for which research strategies are prepared. One of these high-priority topics is mercury risk assessment and  
risk management.

19 The *Mercury Research Strategy* describes ORD's strategic approach to a research program for mercury.  
The strategy presents the key scientific questions to be answered for mercury risk assessment and risk management  
22 over the next five years, along with their associated research needs. It also describes the rationale for, and the  
expected benefits of, EPA's mercury research program. Finally, the strategy outlines the relative emphasis and  
timing of the research activities. ORD expects the *Mercury Research Strategy* to guide development of more  
25 detailed implementation plans and serve as a resource for Agency managers who must make decisions about  
research priorities and budgets. It also may be of use to outside entities in guiding their research.

28  
31 XXX XXXX  
Acting Deputy Assistant Administrator for Science, ORD

1  
4  
7  
10  
13  
16  
19  
22  
25  
28  
31  
34  
37

# PEER REVIEW

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

Initial Internal Agency Review: September 1998  
ORD Science Council: Final clearance November 1998  
Lead Reviewers Lee Mulkey, Ecology Associate  
National Risk Management Research Laboratory

Submitted for Comments  
to the . . . .

External Peer Review:  
Reviewers:

Coordinated by:

Final Acceptance by ORD:

ORD Executive Lead: William Farland, NCEA

TABLE OF CONTENTS

1

4 LIST OF FIGURES/LIST OF TABLES ..... vi

7 ACKNOWLEDGMENTS ..... vii

ACRONYMS ..... viii

10 EXECUTIVE SUMMARY ..... x

13 1. INTRODUCTION ..... 1

16 2. THE REASONS FOR A MERCURY RESEARCH STRATEGY ..... 10

19 3. MERCURY RESEARCH STRATEGY GOALS AND PRIORITIES ..... 15

22 4. KEY SCIENTIFIC QUESTIONS ..... 26

25 5. MERCURY RESEARCH STRATEGY IMPLEMENTATION ..... 49

28 6. REFERENCES ..... 52

APPENDIX 1 ..... 54

1  
4  
7  
10  
13  
16  
19  
22  
25

**LIST OF FIGURES**

- 1. The cycle of mercury and methylmercury in the environment from source to receptor ..... 3
- 2. Mercury-based fish consumption advisories for the United States, December 1997 (EPA, 1998 - Bigler) ..... 7
- 3. Research emphases for *Mercury Research Strategy* key scientific questions (FY 2000 -- FY 2004) ..... 21

**LIST OF TABLES**

- 1. Summary of major sources of anthropogenic mercury air emissions (U.S. EPA, 1997) ..... 3
- 2. EPA commitments that support development of the Mercury Research Strategy ..... 11
- 3. Important international opportunities that support the development of the *Mercury Research Strategy* ..... 13

## ACKNOWLEDGMENTS

Preparation of the *Mercury Research Strategy* was led by the ORD and included staff from EPA's Program Offices and Regions. Co-leaders were Jonathan Herrmann of the National Risk Management Research Laboratory (NRMRL) and Kathryn Mahaffey of the National Center for Environmental Assessment (NCEA), both of ORD. Major contributors included:

**Human Health Team:** Kathryn Mahaffey (Lead), Stan Barone (ORD), Winona Victory (Region IX), and Rita Schoeny (OW)

**Ecological Systems Team:** Herman Gibb (Lead) (ORD), John Nichols (ORD), Randy Wentzel (ORD), Bob Frederick (ORD), Keith Sappington (ORD)

**Fate and Transport Team:** Tom Barnwell (Lead) (ORD), Robert Stevens (ORD), Jerry Stober (Region IV), Alex McBride (OSWER), Arnie Kuzmack (OW), Bob Ambrose (ORD), Barbara Levinson (ORD), Angela Bandemehr (GLNPO), and Russ Bullock (ORD)

**Human Exposure Team:** Arnold Kuzmack (Lead) (OW), Kathryn Mahaffey, Glenn Rice (ORD), Alexis Cain (Region V), and Dale Pahl (ORD)

**Risk Management for Combustion Sources Team:** Douglas McKinney (Lead) (ORD), Jim Kilgroe (ORD), Ellen Brown (OAR), Alex McBride (OAR), Chuck French (OAR), Russ Bullock (ORD), Carl Mazza (ORD)

**Risk Management for Non-Combustion Sources Team:** Ben Blaney (Lead) (ORD), Patricia Erickson (ORD), Ivars Licis (ORD), Larry Jones (ORD), Carlos Nunez (ORD), Paul Randall (ORD), Donald Sanning (ORD), Frank Anscombe (Region V), Tom Armitage (OW), Rita Chow (OSWER), Mary Cunningham (OSWER), Arnie Kuzmack (OW), Iliam Rosario (OAR), Gary Sheth (Region IX), Gregory Susanke (OPPTS), and Jeri Weiss (Region I)

**Risk Communication Team:** Kathryn Mahaffey (Lead) and Jeffrey Bigler (OW)

Other contributors included: Marilyn Engle (OIA), Jonathan Herrmann, Alan Van Arsdale (Region I), Brian Muehling (OIA) Stanley Durkee (ORD), and Angela Bandemehr (GLNPO), who prepared the international portions. Graphics and tables were prepared by John McCready (ORD). Numerous helpful comments were provided during several reviews by EPA's Mercury Task Force (MTF).

## ACRONYMS

	AMAP	Arctic Monitoring and Assessment Program
4	ATSDR	Agency for Toxic Substances and Disease Registry
	BBDR	Biologically Based Dose Response
	BNS	Bi-National Strategy
7	CEC	Commission on Environmental Cooperation
	CEMs	Continuous Emission Monitors
	CENR	Committee on the Environment and Natural Resources
10	EMAP	Environmental Monitoring and Assessment Program
	EPA	Environmental Protection Agency
	EPRI	Electric Power Research Institute
13	FDA	Food and Drug Administration
	FETC	Fossil Energy Technology Center
	GLWQI	Great Lakes Water Quality Initiative
16	GLNPO	Great Lakes National Program Office
	GPRA	Government Performance and Results Act
	HAPs	Hazardous Air Pollutants
19	HCl	Hydrochloric Acid
	HWIs	Hazardous Waste Incinerators
	LDRs	Land Disposal Restrictions
22	LOAEL	Lowest Observed Adverse Effect Level
	LRTAP	Long Range Transport of Air Pollutants
	MACT	Maximum Achievable Control Technology
25	MeHg	Methylmercury
	MM RCT	Multi-media Research Coordination Team
	MTF	Mercury Task Force
28	MWCs	Medical Waste Combustors
	MWIs	Municipal Waste Incinerators
	NaOH	Sodium Hydroxide
31	NAS	National Academy of Sciences
	NCEA	National Center for Environmental Assessment
	NCHS	National Center for Health Statistics
34	NERL	National Exposure Research Laboratory
	NERRS	National Estuarine Research Reserves System
	NIH	National Institutes of Health
37	NIEHS	National Institute for Environmental Health Sciences
	NHANES	National Health and Nutrition Examination Survey
	NHEERL	National Health and Environmental Effects Research Laboratory
40	NCERQA	National Center of Environmental Research and Quality Assurance
	NEP	National Estuary Program
	NPL	National Priorities List
43	NRMRL	National Risk Management Research Laboratory
	NOAA	National Oceanic and Atmospheric Administration
	NOAEL	No Observed Adverse Effect Level
46	NO <sub>x</sub>	Oxides of Nitrogen
	OAQPS	Office of Air Quality Planning and Standards
	OAR	Office of Air and Radiation
49	OECA	Office of Enforcement and Compliance Assurance



1	OIA	Office of International Activities
	OP	Office of Policy
	OPPTS	Office of Prevention, Pesticides, and Toxic Substances
4	ORD	Office of Research and Development
	ORNL	Oak Ridge National Laboratory
	OSTP	Office of Science and Technology Policy
7	OSW	Office of Solid Waste
	OSWER	Office of Solid Waste and Emergency Response
	OW	Office of Water
10	P <sup>2</sup>	Pollution Prevention
	PBPK	Physiologically Based Pharmacokinetics
	PCBs	Polychlorinated Biphenyls
13	PAME	Protection of the Arctic Marine Environment
	PM	Particulate Matter
	ppm	parts per million
16	RFA	Request for Application
	RfDs	Reference Doses
	SPC	Sulfur-Polymer Cement
19	STAR	Science to Achieve Results
	SFRWB	San Francisco Regional Water Board
	TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
22	TCLP	Toxicity Characteristic Leaching Procedure
	TMDLs	Total Maximum Daily Loads
	USGS	United States Geological Survey
25	USFWS	United States Fish and Wildlife Service
	UNECE	United Nations Economic Commission for Europe
	WC	Wildlife Criteria
28		

# EXECUTIVE SUMMARY

## INTRODUCTION

Environmental contamination from mercury has been recognized for decades as a growing problem for both humans and ecosystems. Mercury, in various oxidation states, is released from a variety of anthropogenic (i.e., human) activities and natural sources, undergoes a series of complicated chemical transformations, and proceeds via several different pathways to humans and wildlife. Since mercury is a metal and does not degrade to simpler compounds, it will always be present in the environment in one form or another. According to the 1997 *Mercury Study Report to Congress*, mercury deposition has increased by a factor of two to five over pre-industrial levels. The most significant releases of mercury in the United States are emissions to the atmosphere from anthropogenic sources, particularly the combustion of fossil fuels containing trace amounts of mercury and the incineration of municipal and medical wastes. Other anthropogenic sources of mercury include industrial processes and the disposal of products containing mercury.

Most of the atmospherically deposited mercury is in the form of inorganic mercury either as a gas or in the particulate phase. The inorganic forms of mercury released into the environment can be converted, by naturally occurring biological processes, into the highly toxic methylmercury species. While sufficient information exists to link methylmercury with adverse neurological and developmental effects, assessing the dose at which adverse effects begin to occur in humans and wildlife requires additional attention. Identifying the intake of fish and marine animals necessary to produce the tissue level of concern is also required. Improvements are needed in emissions estimates from major sources, along with a more comprehensive understanding of the transport, transformation, and fate of the mercury emitted from these sources. Finally, reliable and cost-effective techniques are needed to prevent or control release of mercury from anthropogenic sources. Results from the research described in the *Mercury Research Strategy* are expected to provide the scientific information and technical data to reduce uncertainties limiting the Agency's ability to assess and manage mercury and methylmercury risks. Such information will provide the scientific and technical basis for Agency actions (both voluntary and statutorily mandated) that EPA's Program Offices and Regions will implement over the next decade to reduce anthropogenic mercury and its impact on the environment.

The *Mercury Study Report to Congress* provides an assessment of the magnitude of United States mercury emissions by source, the health and environmental implications of those emissions, and the availability and cost of control technologies. It is the most thorough and comprehensive human health and environmental assessment of mercury available and serves as the cornerstone of the Agency's understanding of the mercury problem. The Report to Congress supports a plausible link between anthropogenic releases of inorganic mercury from industrial and combustion sources in the United States and methylmercury in fish. In addition to the *Mercury Study Report to Congress*, there are a number of other EPA documents driving the preparation of the *Mercury Research Strategy*. The *Clean Water Action Plan* sets a goal to ensure that fish and shellfish are safe to eat; it specifically calls for action on mercury. The *Utilities Air Toxics Report to Congress* identifies hazardous air pollutant emissions from utility boilers and indicates that among the pollutants studied, on balance, mercury releases from coal-fired power plants are of greatest potential public health concern. The *Great Waters Second Report to Congress* lists mercury as one of the 15 Great Waters "Pollutants of Concern." Finally, the Agency's Mercury Task Force (MTF), composed of representatives from the various EPA Program Offices and Regions, has prepared the *EPA Action Plan for Mercury* as part of the Agency's multi-office strategy for addressing mercury and other pollutants with similar characteristics. This larger effort is being conducted across seven Program Offices, the Great Lakes National Program Office (GLNPO), and the EPA Regions, and is described in *A Multimedia Strategy for Priority Persistent, Bioaccumulative, and Toxic (PBT) Pollutants*.

1     **THE REASONS FOR A MERCURY RESEARCH STRATEGY**

4     Based on the global nature of the mercury problem, the trans-generational human health effects, the effects  
7     on specific sub-populations, the potential for contamination to affect an entire ecosystem, and the need for more  
10    efficient and cost-effective risk management options, ORD senior management identified mercury as a priority  
13    research area starting in FY 2000. The *Mercury Research Strategy* describes a research program that provides  
information, methods, models, and data to address the key scientific questions of greatest concern to EPA, reducing  
uncertainties currently limiting the Agency's ability to assess and manage mercury and methylmercury risks. ORD  
expects that the research strategy will be used to guide the development of a more detailed implementation plan. It  
will act as a resource for EPA managers who must make decisions about future research priorities and budgets. The  
*Mercury Research Strategy* is designed to provide broad indications on where research for mercury will focus over  
the next five years. It is not intended to convey information on specific projects, nor does it provide a detailed  
schedule of outputs or products.

16    EPA's Program Office commitments related to mercury must be met over the coming five to ten years (Table  
19    1). One of the most important commitments is the Office of Air and Radiation's (OAR's) mandates under the Clean Air  
22    Act (as amended in 1990), with particular emphasis on OAR's need for technical information and data on the cost and  
25    performance of options (e.g., flue gas treatment, coal cleaning) to more cost-effectively reduce emissions from utility  
28    boilers. The research on utilities described in this document supports a recent settlement agreement (and associated  
schedule) for determining the regulation of mercury air emissions from coal-fired utilities. If a positive determination is  
made to regulate emissions from utility boilers, the Agency will propose a rule in FY 2004 with full compliance by the  
utility industry in FY 2008. Other commitments are the Office of Water's (OW's) near-term rule-making on human  
water quality criteria in FY 2000 and deliberations on wildlife and aquatic water quality criteria for mercury in the out  
years. In addition, the Office of Solid Waste and Emergency Response (OSWER) is reevaluating land disposal  
restrictions on mercury and considering alternatives to mercury recovery and incineration. OSWER is also  
undertaking a voluntary effort to reduce the volume and content of persistent bioaccumulative toxics (PBTs) in  
hazardous wastes through FY 2005.

31    Mercury is recognized internationally as an important pollutant that warrants collaborative study and action.  
34    The Office of Prevention, Pesticides, and Toxic Substances (OPPTS) and GLNPO are undertaking voluntary efforts  
37    to remove mercury from wastes, products, and processes, with a goal of a 50 % reduction by the mid-2000s under  
40    the *Great Lakes Binational Toxics Strategy*. A number of bilateral and multilateral programs offer the United States  
an opportunity to promote and engage in cooperative efforts to better understand and ultimately reduce the risks of  
mercury and methylmercury to both humans and wildlife. While some opportunities are voluntary and some entail  
legally binding commitments, EPA's engagement in international efforts is conducted within the context of its existing  
statutory authority, especially with respect to the Clean Air Act. The Office of International Activities (OIA) is  
advancing an understanding of transboundary mercury transport to the United States from abroad by gathering  
speciated mercury deposition monitoring data. It is engaged with other EPA Offices in advancing Agency and United  
States mercury objectives under agreements on the Long Range Transport of Air Pollutants (LRTAP) in Europe, the  
Commission on Environmental Cooperation (CEC) in North America, and through numerous other international fora.  
Rather than being driven by, or reacting to, international initiatives, the Agency is trying to influence them proactively.

1 Table 1. EPA commitments that support development of the *Mercury Research Strategy*.

Program Office/Region	Regulatory Activities	Fiscal Year Target Date
<b>Office of Air and Radiation</b>		
Settlement Agreement on Utility Regulation	Publish Urban Air Toxics Strategy	1999
Maximum Achievable Control Technology (MACT) Standards	MACT Proposals for Chlorine Production, Municipal Landfills and the ICCR	2000
• Industrial Combustion Coordinated Rulemaking (ICCR)	Regulatory Determination on Mercury Controls for Utilities	2001
• Chlor-Alkali Facilities	Promulgate MACT Proposals for Chlorine Production, Municipal Landfills and the ICCR	2001
• Landfills	Develop Initial Urban Area Source Standards (50%)	2002
Integrated Urban Air Toxics Strategy	Full Compliance with MACT proposals for Chlorine Production, Municipal Landfills and ICCR	2004
	Potential Proposed Rule on Mercury Controls for Utilities	2004
	Potential Promulgated Rule on Mercury Controls for Utilities	2005
	Complete Urban Area Source Standards	2006
	Potential Full Compliance by Utilities Industry	2008
	Full Compliance with Urban Area Source Standards	2009
<b>Office of Water</b>		
Rulemaking on Mercury Water Quality Criteria	Promulgate Analytical Method for Mercury in Water	1999
	Publish Revised Human Health Water Quality Criterion for Mercury	2000
	Publish Results of Survey of Contaminants in Fish Flesh – Including Mercury	2003
<b>Office of Solid Waste and Emergency Response</b>		
Land Disposal Restrictions on Mercury	Revise Land Disposal Restriction for Mercury-bearing Hazardous Wastes	2001
Reduction of Mercury in Hazardous Wastes	Revise Rule for Metals (including Mercury) Solidification/Stabilization	2001
	Reduce Level of Mercury in Hazardous Waste by 50%	2005

37 **RESEARCH CATEGORIES AND KEY SCIENTIFIC QUESTIONS**

40 While the *Mercury Study Report to Congress* supports a plausible link between mercury emissions and the November 1999

1 presence of methylmercury in humans, a number of major uncertainties related to both the risk assessment and risk  
management of mercury and methylmercury remain. In the *Mercury Research Strategy*, these uncertainties have  
4 been posed as seven key scientific questions that need to be addressed. These questions fall into four categories;  
both the categories and the key scientific questions are presented below:

### 7 **Human Health and Wildlife Effects of Methylmercury**

The ORD research program will produce information on the human and wildlife effects of  
methylmercury that augments existing data. Results from this research will be factored into refined mercury  
10 risk assessments that will be used to support future policy decisions on safe mercury levels. For example,  
the research will provide the basis to determine whether infants and young children should be added to the  
sub-populations considered at greatest risk. The research results will also assist States and Regions in  
13 deciding when fish consumption advisories are needed to protect public health from mercury pollution. The  
key scientific questions are:

16 **Key Scientific Question #1 (Human Health):** *What critical changes in human health are  
associated with exposure to environmental sources of methylmercury in the most susceptible  
human sub-population?*

19 **Key Scientific Question #2 (Ecological Systems):** *What are the risks associated with  
methylmercury exposure to valued wildlife species and other significant ecological receptors?*

### 22 **Mercury Transport, Transformation, and Fate**

25 The ORD research program will improve information on the transport, transformation, and fate of  
mercury in the environment. Results of this research will provide an improved understanding of the  
environmental fate and transport of mercury, allowing the Agency to quantify how levels of methylmercury in  
28 fish will be reduced by reductions in U.S. sources or how much of this mercury is contributed by United  
States emissions relative to other sources of mercury (such as natural sources and re-emissions from the  
global pool). This issue is critical to establishing cost-effective controls on mercury by helping identify the  
31 sources having the greatest impact on a particular ecosystem. The key scientific question is:

34 **Key Scientific Question #3 (Transport, Transformation, and Fate):** *How much methylmercury  
in fish consumed by the U.S. population is contributed by U.S. emissions relative to other sources  
of mercury (such as natural sources, emissions from sources in other countries, and re-emissions  
from the global pool); how much and over what time period, will levels of methylmercury in fish in  
37 the U.S. decrease because of reductions in environmental releases from United States sources?*

### 40 **Human Exposure to Methylmercury Through the Aquatic Food Chain**

43 The ORD research program will improve information on the actual levels of methylmercury to which  
humans and wildlife are exposed. Results from this research will provide a better understanding of the size  
46 of the population at risk and the linkages between the concentration of methylmercury in fish, levels of  
ambient mercury in the environment, and source emissions. EPA Program Offices and others (e.g., States,  
international community) will incorporate this information into future risk assessments and will also apply the

1 results to identify source categories where reductions have had, or will have, the greatest benefit. The key  
scientific question is:

4 **Key Scientific Question #4 (Human Exposure):** *How much methylmercury are humans exposed  
to, particularly what are the exposures of women of child-bearing age and children among highly-  
7 exposed population groups; what is the magnitude of uncertainty and variability of mercury and  
methylmercury toxicokinetics in children?*

### 10 Risk Management of Mercury and Methylmercury

10 The ORD research program will provide information on techniques that can be used to manage any  
adverse mercury and methylmercury risks and inform the public about them. Results of this research will  
13 provide improved emissions information and data on the cost and performance of control technologies and  
prevention options for priority source categories. OAR, OW, OSWER, and other Program Offices will use  
16 the research results to inform development of regulations for sources where the Agency has a statutory  
responsibility to address mercury releases. The results will also assist States, Regions, and the private  
sector in determining how specific technologies or prevention approaches can be used to meet emissions  
19 standards or voluntary reduction targets that have been negotiated with EPA and the international  
community. The key scientific questions are:

22 **Key Scientific Question #5 (Risk Management for Combustion Sources):** *How much can  
mercury emissions from coal-fired utility boilers and other combustion systems be reduced with  
innovative mercury control technologies; what is the relative performance and cost of these new  
25 approaches compared to currently available technologies?*

28 **Key Scientific Question #6 (Risk Management for Non-combustion Sources):** *What is the  
magnitude of contributions of mercury releases from non-combustion sources; how can the most  
significant releases be minimized?*

31 **Key Scientific Question #7 (Risk Communication):** *How does EPA effectively inform members  
of susceptible sub-populations of the health risks posed by mercury and methylmercury  
contamination of fish and seafood?*

34 Answers to these key scientific questions will provide the scientific and technical basis for EPA's actions over  
the next decade to reduce the impacts on humans and wildlife associated with anthropogenic mercury and  
methylmercury.

### 37 Research Priorities and Emphases

40 In developing the *Mercury Research Strategy*, ORD identified four criteria for prioritizing research  
areas under each of the key scientific questions. These criteria are: (1) supports the goals and objectives of  
43 ORD's Strategic Plan, (2) provides timely scientific information and data to inform Agency decisions, (3) fills  
data and information gaps not addressed by other organizations, and (4) can be conducted or managed by  
ORD personnel with the appropriate technical expertise. With respect to the second criterion, extensive  
46 discussions with the Mercury Task Force and other Program Office and Regional staff (See Table 1)  
resulted in the following emphases for the seven key scientific questions over the five-year life of the  
research strategy. In the early years, ORD's research will focus on risk management for combustion  
sources. As the emphasis on combustion sources decreases in the later years of the research strategy,

1 increased emphasis will be placed on non combustion sources and mercury transport, transformation, and  
fate. Human exposure and risk communication research will remain steady throughout the five-year time  
4 frame. With respect to research on the human health and wildlife effects of methylmercury, human health  
research will remain steady while research on ecological systems will increase.

## 7 RESEARCH STRATEGY FORMAT AND AUDIENCE

10 The *Mercury Research Strategy* presents the goal and scientific questions and associated research  
areas, and shapes the agenda for EPA's mercury research program. It focuses on providing information,  
13 methods, models, and data to address the key scientific questions of greatest interest to EPA. The scientific  
information and technical data provided will reduce uncertainties that limit the Agency's ability to assess and  
manage mercury and methylmercury risks. The *Mercury Research Strategy* is structured to convey the  
above information as follows:

- 16 ▶ Chapter 1.0 introduces the complex challenges associated with mercury from source to  
receptor, including discussion of mercury emissions and releases; mercury transport,  
19 transformation, and fate; impacts of methylmercury on human and wildlife health; and  
mercury and methylmercury risk management.
- 22 ▶ Chapter 2.0 presents the reasons for the *Mercury Research Strategy*, including regulatory  
commitments on mercury by Agency programs; voluntary efforts to prevent or minimize  
25 mercury in products, processes, and wastes; and international opportunities to reduce  
mercury on a global scale.
- 28 ▶ Chapter 3.0 details ORD activities and priorities by identifying seven key scientific  
questions and associated research areas. The questions address changes in human  
31 health and wildlife species exposed to methylmercury, transport of mercury and fate of  
methylmercury in fish consumed by the United States population, the variability in  
34 methylmercury impacts in children and other susceptible sub-populations, releases from  
coal-fired utility boilers and other combustion and non-combustion sources, and effective  
37 methods of communicating health risk information on methylmercury contamination to  
susceptible sub-populations in the United States. This chapter outlines the process of  
setting priorities for mercury research and describes the relative emphasis and timing for  
40 the various research areas. Finally, it presents a general overview of other Federal and  
private organizations conducting research and gathering information on mercury and  
methylmercury.
- 43 ▶ Chapter 4.0 details research areas and supporting descriptions associated with each of  
the seven key scientific questions. Each description includes background, program  
46 relevance, prioritized research needs, and measures of success.
- ▶ Chapter 5.0 identifies issues beyond research that deserve attention and are supportive of  
the research strategy goal and the seven key scientific questions and associated research  
areas. It also describes implementation of the research strategy, including engagement  
and partnership with a variety of stakeholders (e.g., regulated entities, environmental  
groups, community decision-makers at all levels, the general public, international entities)  
and product delivery and use of research results.

49 ORD expects the research strategy will be used to guide development of more detailed implementation

1 plans and as a resource for Agency managers who must make decisions about future research priorities  
and budgets.

4           There are several intended audiences for the *Mercury Research Strategy*. The strategy is of  
particular interest to EPA's Program Offices and Regions because, when implemented, it will provide them  
with data and technical information to assist in regulatory and policy decision making over the next several  
7 years. While ORD's internal Agency customers are a primary audience for research products from the  
strategy, numerous other groups and organizations are interested by, or have a stake in, the research that  
will be conducted. Examples of these groups or organizations, stakeholders if you will, are (1) the United  
10 States Congress, (2) regulated entities, (3) environmental groups, (4) community decision-makers at all  
levels, and (5) the general public. Internationally, foreign governments and multinational groups also will be  
interested in the products of this research strategy.

13



1

# 1. INTRODUCTION

4

Mercury cycles in the environment as a result of natural and anthropogenic (i.e., human) activities. According to EPA's *Mercury Study Report to Congress*, (EPA, 1997a), mercury accumulates most efficiently in the aquatic food web as methylmercury. Although the major environmental risks are associated with organic forms of mercury (i.e., methylmercury), environmental releases are almost always in the inorganic form<sup>1</sup>. In a very complex transformation, inorganic mercury that is emitted and deposited in soil and water is biologically converted to methylmercury. Nearly all of the mercury that accumulates in fish tissue is methylmercury<sup>2</sup>. Inorganic mercury, which is less efficiently absorbed and more readily eliminated from the body than methylmercury, does not tend to bioaccumulate. Human and wildlife exposure to methylmercury occurs almost exclusively through consumption of fish. Predators at the top of the aquatic food web generally exhibit higher methylmercury concentrations than those lower in the food web.

7

10

13

16

Environmental contamination from mercury has been recognized for decades as a problem to humans and wildlife. Human epidemics of methylmercury poisoning, occurring in multiple countries, have established the toxicity of this chemical to the nervous system. Fish-eating (i.e., piscivorous) wildlife are also affected by ingestion of methylmercury. However, only with the publication of the *Mercury Study Report to Congress* was a plausible linkage between emissions and environmental concentrations established and a quantitative risk assessment of methylmercury in fish performed. Reducing risks from methylmercury is difficult because of the wide variety of sources that contribute mercury to the environment. Likewise, mercury releases can be in several different inorganic forms (e.g., elemental mercury vapor, gas-phase ionic mercury, particulate-phase mercury). While sufficient information exists to link methylmercury exposure to adverse neurological and developmental effects, additional information on the mechanisms causing these effects, other health effects (e.g., immune system impacts), and effects on wildlife is needed to reduce risk assessment uncertainties. Assessing the dose of methylmercury at which adverse effects begin to occur in humans and wildlife requires additional attention, as does identifying the intake by fish and marine mammals needed to produce a tissue level of concern. In addition, improvements are needed in emissions estimates from key sources such as electric utilities and chlor-alkali facilities. Options to reduce emissions have either not been identified or are expensive.

19

22

25

28

31

34

37

The *Clean Water Action Plan* (EPA, 1998a) describes mercury as a complex environmental challenge. Mercury is released from a variety of sources, exhibits a complicated chemistry, and proceeds via several different pathways to humans and wildlife (Figure 1.). As mercury is a natural element, it will not degrade to simpler compounds. Once released, mercury will continue to cycle through the environment until it is sequestered (i.e., trapped in lake or ocean sediments). According to the *Mercury Study Report to Congress*, mercury fluxes and budgets in water, soil, and other media have increased by a factor of two to five over pre-industrial levels (EPA, 1997a). As the quantity of available mercury in the environment has

---

<sup>1</sup> In the *Mercury Study Report to Congress*, methylmercury was identified as the chemical species of mercury of greatest environmental concern. For a discussion of adverse human health effects of inorganic mercury, the reader is referred to Volume V of the *Mercury Study Report to Congress* and to the toxicology profile on mercury from the Agency for Toxic Substances and Disease Registry (ATSDR) (ATSDR, 1999).

<sup>2</sup> For the purposes of the *Mercury Research Strategy*, "mercury" refers to all forms of the element prior to methylation. Adverse human and ecological effects of the element occur from methylmercury exposures reflecting the chemical species bioconcentrated in the aquatic food web. Consequently, the term "methylmercury" is used when describing mercury in fish and the adverse health effects of mercury. When describing Agency programs, efforts, and documents the generic term "mercury" is used for all chemical species of mercury.

1 increased, so have the risks of neurological and reproductive problems for humans and wildlife, making it a  
pollutant of considerable concern. The goal of the research in this strategy is to provide the scientific  
4 information and technical data needed to reduce uncertainties limiting the Agency's ability to assess and  
manage mercury and methylmercury risks. This *Mercury Research Strategy* focuses on providing  
information, methods, models, and data to address the key scientific questions of greatest concern to EPA.  
7 Results from this research are expected to support future actions (both voluntary and statutorily-mandated)  
that EPA's Program Offices and Regions will implement over the next decade to reduce anthropogenic  
mercury and its impact on the environment.

## 10 1.1 MERCURY EMISSIONS AND RELEASES

13 Mercury has been widely used in industrial applications because of its unique properties. It  
conducts electricity, responds to temperature and pressure changes, and forms alloys with almost all metals.  
In the electrical industry, mercury is used in fluorescent lamps, as part of wiring devices, and with  
16 instruments that measure temperature and pressure. It is also a component of dental amalgams used in  
restoring teeth. In addition to specific products, mercury is used in numerous industrial processes. The  
largest manufacturing use of mercury in the United States is associated with the production of chlorine and  
caustic soda by mercury-cell chlor-alkali plants (MCCP). Mercury is also used in amalgamation with other  
19 metals, as an antifungal agent in wood preserving, and as a solvent for reactive and precious metals (EPA,  
1997a).

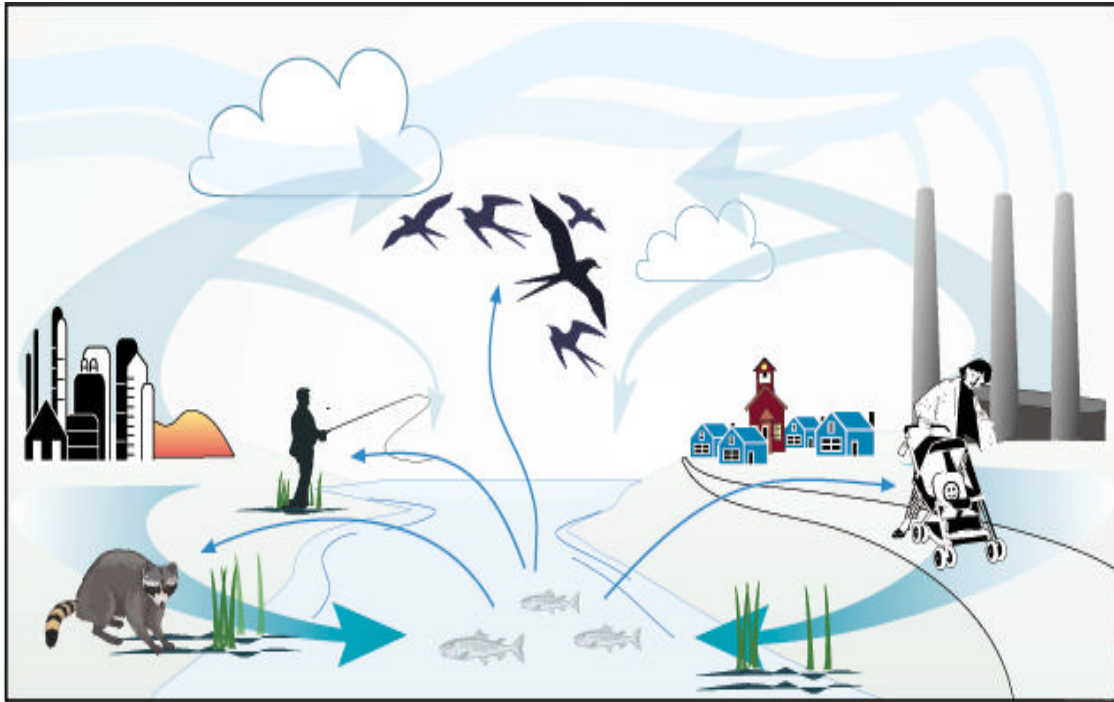
22 Mercury-bearing wastes are generated from manufacturing processes and the disposal of  
consumer products. In 1995 an estimated 245 tons of mercury was discarded in municipal waste streams  
(EPA, 1997a). Most of this waste was either incinerated or placed in landfills. Industrial hazardous wastes  
25 with high mercury concentrations are currently incinerated or retorted. Retorting involves the heating of  
mercury-containing wastes with the mercury converting to a gas that is captured and then condensed back  
to the metallic form. The intentional use of mercury in commercial products in the United States declined by  
28 more than 75 % from 1988 to 1996 (EPA, 1997a). This reduction is largely due to the private sector's efforts  
to eliminate the use of mercury in products and processes. Along with this commercial use reduction, an  
increase in the recycling and recovery of mercury has resulted in a supply that now exceeds domestic  
31 demand.

34 The most significant releases of mercury to the environment in the United States are emissions to  
the atmosphere, which can be characterized as released by anthropogenic activities (i.e., human), released  
from geologically bound mercury through natural processes (i.e., natural), and released through mass  
transfer to the atmosphere by biologic/geologic processes for previously deposited mercury (i.e., "re-emitted")  
37 (EPA, 1997a)<sup>3</sup>. The *Mercury Study Report to Congress* presents an inventory, based on 1994/1995 data, of  
anthropogenic air releases of mercury in the United States summarized in Table 2. The source categories  
presented in the table each constitute more than one percent of the total contribution of mercury to the  
40 atmosphere from human activity. The greatest releases of anthropogenic mercury to the environment are  
from combustion of fuel containing trace amounts of mercury, industrial processes that use mercury, and  
disposal (especially by incineration) of products that contain mercury either as an intentional constituent or  
43 as an impurity. Anthropogenic mercury sources within the United States emit approximately

---

<sup>3</sup> With respect to this last category, a large portion of the deposited mercury is the result of past anthropogenic releases as well as releases from natural sources that heretofore have been sequestered (e.g., arctic tundra, ice sheets, oceans and wetlands) (Lindberg, 1995).

1 Figure 1. The cycle of mercury in the environment from source to receptor.



4  
7 Table 2. Summary of major sources of anthropogenic mercury air emissions (EPA,1997a).

Source	%
Coal-fired electric utility boilers	32
Municipal waste combustors	18
Coal- and oil-fired commercial/industrial boilers	18
Medical waste incinerators	10
Chlor-alkali plants	4
Portland cement plants	3
Oil-fired residential boilers	2
Other sources of Mercury	13

1  
4  
7  
10  
13  
16  
19

*Fish consumption dominates the pathway for human and wildlife exposure to methylmercury. The Mercury Report to Congress supports a plausible link between anthropogenic releases of mercury from industrial and combustion sources in the United States and methylmercury in fish. However, these fish methylmercury concentrations also result from existing background concentrations of mercury (which may consist of mercury from natural sources, as well as mercury which has been re-emitted from the oceans or soils) and deposition from the global reservoir (which includes mercury emitted by other countries). Given the current scientific understanding of the environmental fate and transport of this element, it is not possible to quantify how much of the methylmercury in fish consumed by the U.S. population is contributed by U.S. emissions relative to other sources of mercury (such as natural sources and re-emissions from the global pool).*

- Excerpt from the Mercury Study Report to Congress, December 1997, (Volume 1, Executive Summary), <http://www.epa.gov/oar/mercury.html>

150 tons of mercury per year (EPA, 1997a)<sup>4</sup>. One-third of the U.S. anthropogenic emissions (about 52 tons) are deposited through wet and dry deposition within the contiguous 48 States. The remaining two-thirds is transported outside the United States and enters the global mercury cycle. It is estimated that an additional 35 tons per year are deposited in the United States from the global cycle (i.e., anthropogenic, natural, and re-emitted sources) (EPA, 1997a). EPA anticipates that anthropogenic mercury emissions in the U.S. will be reduced over the next several years as a consequence of mercury emission controls, but it is expected that without similar actions in other countries, releases globally will increase mercury deposition in the United States (Pirrone, et.al., 1996).

22 In addition to releases via emissions, mercury is released via other means, including discharges  
from industrial sources and waste sites and releases of methylmercury from sediments to water bodies.  
25 Release of mercury in water discharges is believed to be small compared to atmospheric emissions, but it  
can have significant local effects. Mercury discharges to surface waters from abandoned gold and mercury  
mines in the western United States are believed to be the cause of fish advisories for methylmercury in a  
28 number of streams and lakes. An example is the contamination of Clear Lake in California by the Sulphur  
Mercury Mine Superfund Site. An international example of mercury pollution from an industrial source exists  
in Natal, South Africa, where the Thor Chemical Plant houses large quantities of mercury wastes that have  
31 leaked/leached to the nearby environment and groundwater. The South African government has assigned a  
high priority to addressing this situation. Releases of methylmercury from sediments have not been well  
quantified, but high concentrations of methylmercury in sediments often coincide with high concentrations of  
methylmercury in fish tissue and result in mercury fish consumption advisories (EPA, 1999a).

## 34 1.2 MERCURY TRANSPORT, TRANSFORMATION, AND FATE

37 The air transport and deposition patterns in the United States for mercury emissions depend on  
various factors, including the form of mercury emitted, the location of the emissions source, the stack height  
of the source, the topography near the source, and prevailing air circulation patterns. For example,  
40 anthropogenic point sources (e.g., coal-fired electric utility boilers, municipal waste combustors) emit  
elemental gaseous mercury ( $Hg^0$ ), divalent gaseous mercury ( $Hg^{+2}$ ), and particulate-phase mercury. The  
chemical and physical properties of these different forms dominate their behavior in the environment and  
43 their significance as contaminants, resulting in:

---

<sup>4</sup> Although no official EPA estimates have been made and, according to the *Mercury Study Report to Congress*, "The current state of knowledge of mercury emissions ... does not allow for an accurate assessment of either natural or re-emitted mercury emissions," it is possible that natural and re-emitted emissions associated with contaminated soils and water bodies within the United States could add significantly to this value (EPA, 1997a).

1 Local scale impacts, which result from deposition within a 30-mile radius of an emissions source. For  
example, a source emitting primarily Hg<sup>+2</sup> can be expected to have a relatively high percentage of mercury  
deposited within the 30-mile radius via wet deposition (EPA, 1997a).

4 Regional scale impacts, which result from either wet or dry deposition associated with long-range transport  
of emissions over hundreds of miles dispersed across wide areas. For example, the *Mercury Study Report  
to Congress* (1997a) described the regional impacts of stack emissions in the United States. According to  
that study, the highest deposition rates in the U.S. are predicted to occur in the southern Great Lakes and  
Ohio River Valley, the Northeast and scattered areas in the Southeastern United States.

10 Global scale impacts, which result from Hg<sup>0</sup> emissions that become part of the global emissions pool, where  
they can remain for a year or more before being converted and subsequently depositing (wet and dry  
deposition) on soil or water. For example, recent studies indicate that in Arctic air, mercury may be oxidized  
and the deposition of mercury may be enhanced (Schroeder, et.al., 1998).

16 Anthropogenic mercury that is released directly to land or water bodies, or is deposited on them, undergoes  
a complex and not-well-understood series of transformations. These transformations -- generally in  
wetlands, aquatic systems, and sediments -- convert some of the mercury to methylmercury. Not only is  
methylmercury much more toxic to humans and wildlife than the inorganic forms, it is more likely to  
bioaccumulate in fish tissue. This ability of methylmercury to bioaccumulate results in food chain impacts  
yielding increased concentrations of methylmercury in both humans and wildlife. The amount of methylation  
and accumulation varies greatly from one water body to another, depending on a number of factors,  
including the acidity and the trophic status of the water body.

### 25 1.3 IMPACTS OF METHYLMERCURY ON HUMAN AND WILDLIFE HEALTH

28 Methylmercury is known to have  
toxic effects in humans, including permanent  
damage to the brain and kidneys. The  
nervous system is particularly sensitive to  
mercury and methylmercury. The impact of  
methylmercury on wildlife is related to the  
species' position in the food web and whether  
the animal is primarily a fish-eater (i.e.,  
piscivorous). The bioaccumulation of  
methylmercury will generally have the  
greatest effects on wildlife high in the food  
web. The exposure route of methylmercury  
production in aquatic systems indicates that  
animals that primarily feed on fish and those  
that prey on these fish eaters will have the  
greatest risk of toxic effects associated with  
methylmercury exposure. The *Mercury Study  
Report to Congress* identified the mink, river  
otter, kingfisher, loon, osprey, and bald eagle  
as examples of species with increased risk  
(1997a). Reported sub-chronic effects have  
included neurological damage and reduced  
reproductive levels.

*Mercury is a known human toxicant. Clinically observable neurotoxicity has been observed following exposure to high amounts of mercury (for example "Mad Hatters Disease"). Consumption of highly contaminated food also has produced overt mercury neurotoxicity. Generally, the most subtle indicators of methylmercury toxicity are neurological changes. The neurotoxic effects include subtle decrements in motor skills and sensory ability at comparatively low doses to tremors, inability to walk, convulsions and death at extremely high exposures.*

\*\*\*\*\*

*Concentrations of mercury in the tissues of wildlife species have been reported at levels associated with adverse effects in laboratory studies of the same species. However, field data are insufficient to conclude whether piscivorous wading birds or mammals have suffered adverse effects due to airborne mercury emissions. Modeling analyses suggest that it is probable that individuals of some highly exposed wildlife sub-population are experiencing adverse effects due to airborne mercury.*

- Excerpts from the Mercury Study Report to Congress, December 1997, (Volume 1, Executive Summary), <http://www.epa.gov/oar/mercury.html>

1           When mercury is observed in humans and wildlife, it is the culmination of an involved process  
having impacts at local, regional, and global scales. The *Mercury Study Report to Congress* concluded that  
the primary route of human exposure to mercury is through the consumption of fish contaminated by  
4 methylmercury (EPA, 1997a). As illustrated in Figure 2, thirty-nine States have some form of mercury fish  
advisory for their water bodies. Statewide advisories for mercury occur consistently across the Northeastern  
7 States; Gulf Coast States have advisories in all coastal waters. Mercury is, by far, the major reason for fish  
advisories, and there is an increasing trend in the number of advisories due to its presence in the Nation's  
waters. Based on its analysis of dietary surveys, EPA concluded that typical fish consumers in the United  
10 States are not in danger of ingesting harmful levels of methylmercury. This is a reflection of the relatively low  
levels of fish consumed by the typical U. S. citizen. However, EPA's risk assessment also concluded that  
between one and three percent of women of child-bearing age (e.g, between the ages of 15 and 44) eat  
13 sufficient amounts of fish for their fetuses to be at risk from methylmercury exposure, depending on the  
methylmercury concentrations in the fish.

16           Also, based on the same analysis of United States dietary survey data from the mid-1990s, EPA  
estimated the percentage of people from different sub-populations who consume methylmercury in excess of  
the Reference Dose (RfD)(EPA, 1997a)<sup>5</sup>. Among white/non-Hispanic sub-populations the fraction above the  
RfD was 9.0 %, among black/non-Hispanics, 12.7%, and among persons of Asian/Pacific Islander ethnicity,  
19 Native American tribal members, and non-Mexican Hispanics (e.g., persons from Puerto Rico and other  
Caribbean islands) 16.6 %. Among women of childbearing age (i.e., 15 through 44 years) seven % of the  
more than 58 million women in the group (i.e., more than 4 million women) are exposed to methylmercury  
22 from fish at levels in excess of the RfD, using month-long exposures as the basis for calculation. Depending  
on the methylmercury concentration in the fish, women may be at increased risk and may be putting their  
fetuses at risk of the subtle neurological and developmental effects associated with methylmercury  
25 exposure. In addition to women of child-bearing age and their fetuses, populations of concern include young  
children whose nervous systems continue to develop postnatally. Exposures to children under 6 years of  
age are of particular concern. An additional group at risk are sub-populations who depend heavily on fish  
28 and piscivorous mammals in their diets (e.g., some Alaskan native groups).

---

<sup>5</sup>A reference dose (RfD) is defined in the following way by EPA: an estimate with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive sub-populations) that is likely to be without an appreciable risk of deleterious effects during a lifetime. (EPA, 1997). At the RfD or below, exposures are expected to be safe. The risk following exposures above the RfD is uncertain, but risk increases as exposures to methylmercury increase.

1

4

7

10

13

16

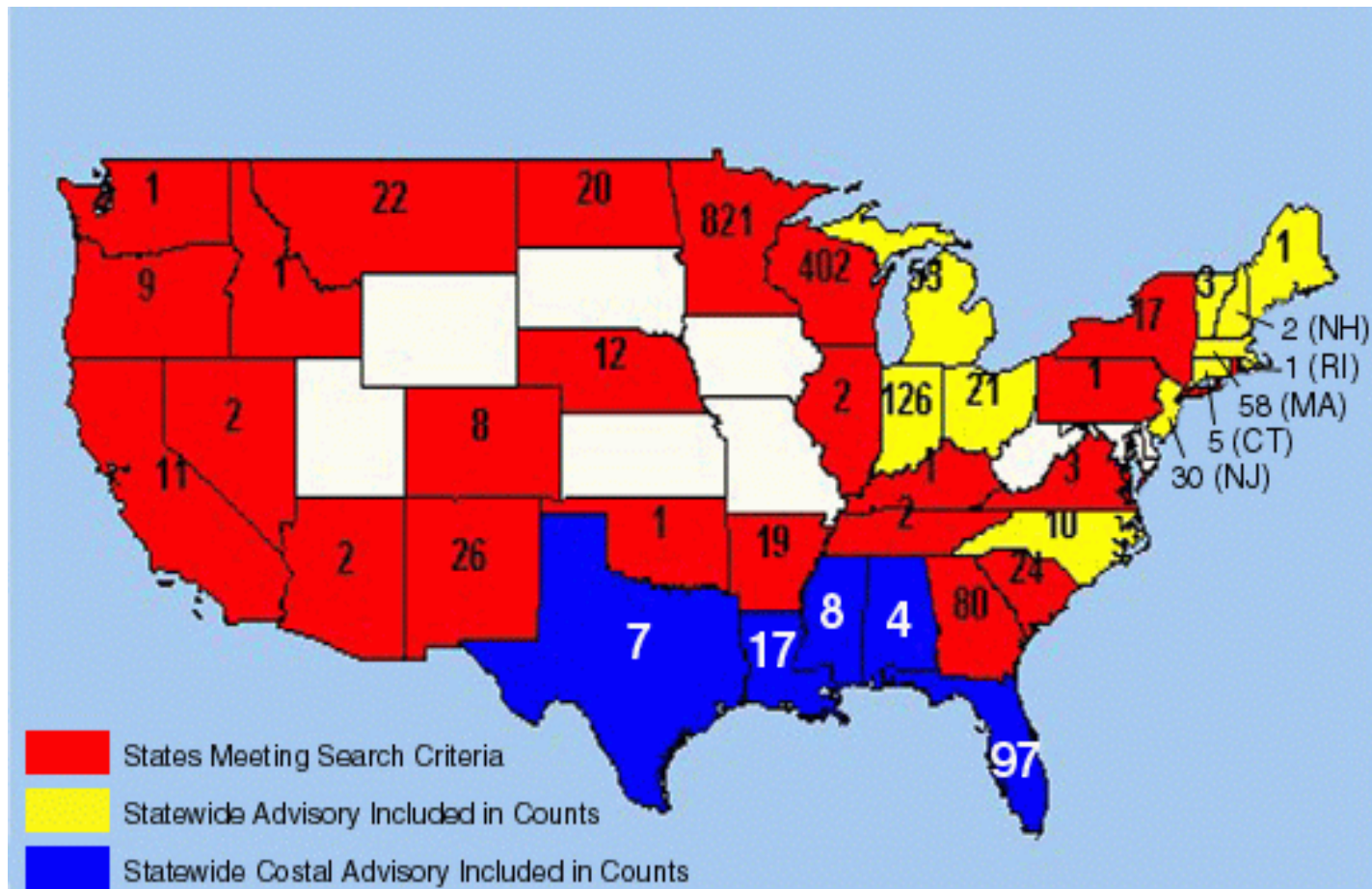
19

22

25

28

31



34

Figure 2. Mercury-based fish consumption advisories for the United States, December 1998 (EPA, 1999a).

#### 1.4 MERCURY RISK MANAGEMENT OPTIONS

Managing emissions and other releases of mercury requires a variety of approaches ranging from to address the mercury problem was identified in the *Mercury Study Report to Congress* (1997a). Some actions, such as replacing mercury used in paints and batteries and injection of activated carbon into the flue gas of municipal waste combustion units and medical waste incinerators, are part of the technological options already used to reduce releases and emissions product substitution to end-of-the-pipe treatment. There is a need to develop information for a mix of strategies for managing mercury. Other options, such as removing mercury-containing products from waste streams (separation), coal cleaning, fuel switching, advanced mercury sorbents, sediment remediation methods, substitutes for mercury used in electronic switches and thermometers, and conversion of chlor-alkali plants from a mercury electrolytic cell to a membrane cell process, are available or under development. Life-cycle tools to evaluate how this mix of options could best be deployed to maximize risk reduction and minimize cost are in various stages of development; however, current tools are adequate to conduct an initial life-cycle assessment (LCA) for a variety of mercury sources. Further development and evaluation of process changes, product substitutions, and innovative technologies will provide additional options to address the mercury problem. Cooperative research between the public and private sectors is underway to further develop the most promising options, refine their costs, and determine what combinations would result in the greatest reduction of risks to humans and wildlife.

*Cost effective opportunities to deal with mercury during the product life cycle, rather than just at the point of disposal need to be pursued. A balanced strategy which integrates end-of-pipe control technologies with materials substitution and separation, design-for-environment and fundamental process changes is needed. In addition, intervention efforts to reduce mercury emissions as well as greenhouse gases will play an important role in reducing inputs to the global reservoir.*

- Excerpt from the Mercury Study Report to Congress, December 1997, (Volume VIII, An Evaluation of Mercury Control Technologies and Costs), <http://www.epa.gov/oar/mercury.html>

#### 1.5 RESEARCH STRATEGY FORMAT

The *Mercury Research Strategy* presents the goal and key scientific questions and associated research areas, and shapes the agenda for EPA's mercury research program. It focuses on providing information, methods, models, and data to address the key scientific questions of greatest interest to EPA. The scientific information and technical data provided will reduce uncertainties that currently limit the Agency's ability to assess and manage mercury and methylmercury risks. The *Mercury Research Strategy* is structured to convey the above information as follows:

- ▶ Chapter 1.0 introduces the complex challenges associated with mercury from source to receptor, including discussion of mercury emissions and releases; mercury transport, transformation, and fate; impacts of methylmercury on human and wildlife health; and mercury and methylmercury risk management.
- ▶ Chapter 2.0 presents the reasons for the *Mercury Research Strategy*, including regulatory commitments on mercury by Agency programs; voluntary efforts to prevent or minimize mercury in products, processes, and wastes; and international opportunities to reduce mercury on a global scale.
- ▶ Chapter 3.0 details ORD activities and priorities by identifying seven key scientific questions and associated research areas. The questions address changes in human health and wildlife species exposed to methylmercury, transport of mercury, and fate of methylmercury in fish consumed by the United States population, the variability in



1 methylmercury impacts in children and other susceptible sub-populations, releases from  
4 coal-fired utility boilers and other combustion and non-combustion sources, and effective  
7 methods of communicating health risk information on methylmercury contamination to  
susceptible sub-populations in the United States. This chapter outlines the process of  
setting priorities for mercury research and describes the relative emphasis and timing for  
the various research areas. Finally, it presents a general overview of other Federal and  
private organizations conducting research and gathering information on mercury and  
methylmercury.

10 ▶ Chapter 4.0 details research areas and supporting descriptions associated with each of  
the seven key scientific questions. Each description includes background, program  
relevance, prioritized research needs, and measures of success.

13 ▶ Chapter 5.0 identifies issues beyond research that deserve attention and are supportive of  
16 the research strategy goal, the seven key scientific questions, and associated research  
areas of the *Mercury Research Strategy*. It also describes implementation of the research  
19 strategy, including engagement and partnership with a variety of stakeholders (e.g.,  
regulated entities, environmental groups, community decision-makers at all levels, the  
general public, international entities) and product delivery and use of research results.

22 ORD expects the research strategy will be used to guide development of more detailed implementation  
plans and as a resource for Agency managers who must make decisions about future research priorities  
and budgets.

## 2. THE REASONS FOR A MERCURY RESEARCH STRATEGY

The *Mercury Study Report to Congress* was submitted by EPA in December 1997, pursuant to Section 112(n)(1)(B) of the Clean Air Act, as amended in 1990. The report provides an assessment of the magnitude of U. S. mercury emissions by source, the health and environmental implications of those emissions, and the availability and cost of control technologies. It serves as the cornerstone of the Agency's understanding of the problems associated with mercury. As noted earlier, the *Report to Congress* supports a plausible link between anthropogenic releases of mercury from industrial and combustion sources in the United States and methylmercury in fish. While the report indicates that the rapidly changing state-of-the-science on mercury means that it is only a "snapshot" of EPA's current knowledge, it is the most thorough and comprehensive human health and environmental assessment of mercury available.

In addition to the *Mercury Study Report to Congress*, a number of other EPA documents drive the preparation of the *Mercury Research Strategy*. The *Clean Water Action Plan* (EPA, 1998a) sets a goal to improve assurance that fish and shellfish are safe to eat and specifically calls for action on mercury. The *Utility Air Toxics Report to Congress* (EPA, 1998b) identifies hazardous air pollutant emissions from utility boilers and indicates that of the pollutants studied, on balance, mercury releases from coal-fired power plants are of greatest potential public health concern. Also, the *Great Waters Second Report to Congress* (EPA, 1997b) lists mercury among the 15 Great Waters "Pollutants of Concern." Finally, the EPA Program Offices and Regions, via the Mercury Task Force (MTF), have prepared the *EPA Action Plan for Mercury* as part of *A Multimedia Strategy for Priority Persistent, Bioaccumulative, and Toxic (PBT) Pollutants* (Federal Register, 1998). This Mercury Action Plan includes a number of near-term regulatory and voluntary actions that EPA will undertake to address mercury, including the development of the *Mercury Research Strategy*.

### 2.1 REGULATORY AND OTHER DOMESTIC COMMITMENTS TO AGENCY ACTION

The Administration and Congress have both conveyed their interest in mercury and its potential for adverse effects on human health. At the request of the Administration, the National Institutes of Health (NIH) convened a workshop in November 1998 to address the scientific issues that relate to assessment of health effects from exposure to methylmercury. The FY 1999 Congressional budget contains a \$1.0M appropriation for the National Academy of Sciences (NAS) to conduct a study on the appropriate reference dose (RfD) for methylmercury. This latter effort will involve a review of the health research on mercury conducted since the completion of the *Mercury Study Report to Congress*. Information from both the federally sponsored workshop and the NAS study will assist the Agency in re-evaluating the RfD for methylmercury with respect to human health impacts. The NAS report is scheduled for delivery in the Spring of 2000. Development of technical information and data to support Program Office regulatory and court-mandated commitments is a very important ORD role. A number of Program Office commitments related to mercury must be met over the coming five to ten years (Table 3). One of the most important commitments is to the Office of Air and Radiation's (OAR's) implementation of the Clean Air Act, as amended in 1990. Of particular importance is OAR's need for technical information and data on the cost and performance of options (e.g., flue gas treatment, coal cleaning) to more cost-effectively reduce emissions from utility boilers. The research on utilities supports a recent settlement agreement (and associated schedule) with the National Resources Defense Council for determining the regulation of mercury air emissions from coal-fired utilities. If a positive determination is made to regulate emissions from utility boilers, the Agency will propose a rule in FY 2004, with full compliance by the utility industry by FY 2008.

Table 3. EPA commitments that support development of the *Mercury Research Strategy*.

Program Office/Region	Regulatory Activities	Fiscal Year Target Date
<b>Office of Air and Radiation</b>		
Settlement Agreement on Utility Regulation	Publish Urban Air Toxics Strategy	1999
Maximum Achievable Control Technology Standards <ul style="list-style-type: none"> <li>• Industrial Combustion Coordinated Rulemaking (ICCR)</li> <li>• Chlor-Alkali Facilities</li> <li>• Landfills</li> </ul> Integrated Urban Air Toxics Strategy	MACT Proposals for Chlorine Production, Municipal Landfills and the ICCR	2000
	Regulatory Determination on Mercury Controls for Utilities	2001
	Promulgate MACT Proposals for Chlorine Production, Municipal Landfills and the ICCR	2001
	Develop Initial Urban Area Source Standards (50%)	2002
	Full Compliance with MACT proposals for Chlorine Production, Municipal Landfills and ICCR	2004
	Potential Proposed Rule on Mercury Controls for Utilities	2004
	Potential Promulgated Rule on Mercury Controls for Utilities	2005
	Complete Urban Area Source Standards	2006
	Potential Full Compliance by Utilities Industry	2008
	Full Compliance with Urban Area Source Standards	2009
<b>Office of Water</b>		
Rulemaking on Mercury Water Quality Criteria	Promulgate Analytical Method for Mercury in Water	1999
	Publish Revised Human Health Water Quality Criterion for Mercury	2000
	Publish Results of Survey of Contaminants in Fish Flesh – Including Mercury	2003
<b>Office of Solid Waste and Emergency Response</b>		
Land Disposal Restrictions on Mercury Reduction of Mercury in Hazardous Wastes	Revise Land Disposal Restriction for Mercury-bearing Hazardous Wastes	2001
	Revise Rule for Metals (including Mercury) Solidification/Stabilization	2001
	Reduce Level of Mercury in Hazardous Waste by 50%	2005

Other commitments include the Office of Water's (OW's) near-term rule-making on human water quality criteria in FY 2000 and deliberations on wildlife and aquatic water quality criteria for mercury in the out years. In addition, the Office of Solid Waste and Emergency Response (OSWER) is re-evaluating land disposal restrictions on mercury to consider alternatives to mercury recovery and incineration. OSWER is

1 undertaking a voluntary effort to reduce the volume and content of persistent, bioaccumulative toxics (PBTs)  
in hazardous wastes through FY 2005. The Office of Prevention, Pesticides, and Toxic Substances  
(OPPTS) and the Great Lakes National Program Office (GLNPO) are undertaking voluntary efforts to  
4 remove mercury from wastes, products, and processes, with a goal of a 50 % reduction by the mid-2000s  
(EPA, 1997c). In all cases, these are important Agency priorities that benefit from ORD research both in  
7 terms of the assessment of risks to humans and wildlife and the characterization and management of risks  
from sources.

## 10 2.2 INTERNATIONAL OPPORTUNITIES TO ADDRESS MERCURY

13 Mercury is recognized internationally as an important pollutant warranting collaborative study and  
action. A number of bilateral and multilateral programs offer the United States an opportunity to promote and  
engage in cooperative efforts to better understand and ultimately reduce the risks of mercury and  
16 methylmercury (Table 4). While some opportunities are voluntary and others entail legally binding  
commitments, EPA's involvement in international efforts is conducted within the context of its existing  
statutory authority, especially with respect to the Clean Air Act. Rather than being driven by, or reacting to,  
international initiatives on mercury, the Agency is trying to be proactive and influence them. Key  
19 international programs addressing mercury are:

- 22 • The 1998 Aarhus Protocol to the United Nations Economic Commission for Europe  
(UNECE) Convention on Long-Range Transboundary Air Pollution (LRTAP) on Heavy  
Metals (55 member countries in the Northern Hemisphere) (UNECE, 1998);
- 25 • The Arctic Environmental Protection Strategy - Arctic Council, particularly the Protection of  
the Arctic Marine Environment (PAME) and Arctic Monitoring and Assessment Program  
(AMAP) programs (eight member countries) (Arctic Council, 1991);
- 28 • The North American Commission on Environmental Cooperation (NACEC), specifically its  
North American Regional Action Plans (NARAP) (Canada, Mexico, and the United States)  
(CEC, 1998);
- 31 • *The Great Lakes Binational Toxics Strategy: Canada-United States Strategy for the Virtual  
Elimination of Persistent Toxic Substances in the Great Lakes* (Canada and the United  
34 States) (EPA, 1997c); and
- 37 • *The Northeastern States and Eastern Canadian Provinces Mercury Study: A Framework  
for Action* (NESCAUM,, 1998)

40 ORD has made a concerted effort to engage the Office of International Activities (OIA) and those Regions involved in  
the above programs in the preparation and review of the *Mercury Research Strategy*. Each will benefit from the  
scientific information and technical data resulting from the implementation of the strategy.

1 Table 4. Important international mercury opportunities that support the development of the *Mercury Research Strategy*.

Program Office/Region	Multi-national Provisions	Target Date
<b>Office of Air and Radiation</b>		
UNECE LRTAP Convention, Heavy Metals Protocol	Apply BAT to new stationary sources by 2 years after entry into force of protocol	Promulgation of MACT standard
	Apply BAT to existing stationary sources by 8 years after entry into force of protocol	Promulgation of MACT standard
<b>Office of Air and Radiation &amp; Office of Research and Development</b>		
UN ECE LRTAP Convention, Heavy Metals Protocol	Submit domestic emissions inventory updates and research results to support annual assessment of Protocol compliance results	2000 and annually thereafter
<b>Office of International Activities, Office of Research and Development, &amp; Region 10</b>		
Arctic Council (AC) - Arctic Monitoring and Assessment Program	Progress report on 2nd phase of heavy metals assessment	2000
	AC Ministerial report on 2nd phase assessment results	2002
	Final AC Ministerial report on 2nd phase assessment results	2006
<b>Office of Prevention, Pesticides, and Toxic Substances</b>		
CEC North American Regional Action Plan on Mercury	Coordinate involvement in, and represent the United States during, preparation of second phase mercury NARAP	End of 1999
<b>Region 5; GLNPO; OPPTS; all EPA Offices</b>		
The Great Lakes Binational Toxics Strategy	Seek 50% reduction nationally in deliberate use of mercury, and 50% reduction in releases of mercury from sources (air and water) resulting from human activity.	2006
	Virtual elimination of mercury	Beyond 2006
<b>Region 1; all EPA Offices</b>		
The NE Governors-Eastern Canadian Premiers Mercury Action Plan (June 1998)	Virtual elimination of anthropogenic discharge of mercury	2003
	Progress Report	1999

37 **2.3 ALIGNMENT WITH ORD'S STRATEGIC PLAN AND RELATIONSHIP TO OTHER RESEARCH STRATEGIES**

40 ORD's decision to focus on mercury research is predicated on guidance found in the *1997 Update to ORD's Strategic Plan* (EPA, 1997d). This guidance provides the framework and a variety of criteria that ORD uses to determine what research it will emphasize under its various research strategies. ORD determines whether the

1 Agency has a mandate to conduct the research. In the case of mercury, it is clear from Tables 3 and 4 that the  
Agency has a variety of commitments requiring research support. Based on the global nature of the mercury  
4 problem, the trans-generational human health effects, the effects on specific sub-populations, the potential for  
contamination to affect an entire ecosystem, and the need for more efficient and cost-effective risk reduction options,  
ORD senior management determined that mercury met a sufficient number of criteria to be considered a priority area  
7 for investment in FY 2000.

10 Chapter 3.0 explains which mercury research areas ORD will focus on and why those particular research  
areas are a priority. The research areas chosen were designed to build on and complement research conducted  
under other ORD strategies. For example, evaluation of the life-cycle implications of various mercury and  
methylmercury risk management options build on the pollution prevention tools and methods research conducted  
under ORD's *Pollution Prevention Research Strategy* (EPA, 1998c). Similarly, models to determine what  
13 characteristics of aquatic systems promote methylmercury production builds on ecosystem models being generated  
that predict the response of ecosystems to multiple stressors at multiple scales (EPA, 1998d).

1 **3. MERCURY RESEARCH STRATEGY GOAL AND PRIORITIES**

4 A long-term goal has been identified for the *Mercury Research Strategy*. In order to achieve this goal, ORD  
will undertake research that addresses both mercury and methylmercury risk assessment and risk management.  
This research will be conducted by scientists and engineers in ORD laboratories and centers, at universities, by the  
private sector, and with other Federal organizations. ORD will take the lead in integrating the results from this  
7 research into documents that can be used to inform future decisions by

10 **GOAL**  
13 Provide the scientific information and technical data to  
reduce uncertainties currently limiting the Agency's ability to  
16 assess and manage mercury and methylmercury risks.

19 the Agency's Program Offices and Regions. The above *Mercury Research Strategy* goal resides under the Agency's  
Sound Science, Improved Understanding of Environmental Risk, and Greater Innovation to Address Environmental  
Problems Goal (Goal 8). This goal is described in the Agency's strategic plan (EPA, 1997e) and is part of a series of  
goals associated with EPA's commitment to the Government Performance and Results Act. A review of EPA's FY  
2000 summary budget document (EPA, 1999b) suggests that a number of other Agency goals will benefit from the  
research being conducted under the research strategy: Goal 1 – Clean Air; Goal 2 – Clean and Safe Water; Goal 4 –  
Preventing Pollution and Reducing Risk in Communities, Homes, Workplaces, and Ecosystems; Goal 5 – Better  
Waste Management and Restoration of Contaminated Waste Sites, and Emergency Response; Goal 6 – Reduction of  
Global and Cross-Border Environmental Risks; and Goal 7 – Expansion of Americans' Right to Know About Their  
Environment. It is envisioned that the goal for the *Mercury Research Strategy* will be translated into a GPRA sub-  
28 objective under Goal 8's Emerging Risks Objective (8.3).

31 **3.1 KEY SCIENTIFIC QUESTIONS AND RESEARCH AREAS**

34 In preparing the *Mercury Research Strategy*, ORD consulted extensively with the Program Offices and  
Regions, primarily via the Mercury Task Force (MTF). Based on those consultations, seven key scientific questions  
and associated research areas were identified that require ORD's attention. These questions fall into four  
categories. Both the categories and the key scientific questions are summarized below and described in much  
greater detail in Chapter 4.0.

37 **3.1.1 Human Health and Wildlife Effects of Methylmercury**

40 The ORD research program will produce information on the human and wildlife effects of methylmercury that  
augments existing data. The key scientific questions and planned research areas are:

43 **Key Scientific Question #1 (Human Health).** *What initial changes in human health are associated with exposure to  
environmental sources of mercury in the most susceptible human sub-population?*

- 46  Understand mechanisms of mercury's developmental toxicity and link it to exposure data through  
biokinetic models.  
49  Investigate mercury effects on the immune system.

- 1
- Resolve risk assessment uncertainties associated with neural compensation after a developmental insult.

4

Results from this research will be factored into refined mercury risk assessments that will be used to support future policy decisions on safe mercury levels. For example, outputs from the research will provide the basis to determine whether infants and young children should be added to the sub-populations considered at "greatest" risk. The research results will also assist states and Regions in deciding when fish consumption advisories are needed to protect public health from mercury pollution.

7

10

**Key Scientific Question #2 (Ecological Systems).** *What are the risks associated with mercury exposure to valued wildlife species and other significant ecological receptors?*

- 13
- Determine methylmercury effects on avian and mammalian wildlife including differences in species sensitivity, critical target tissues, and kinetics of methylmercury uptake.
  - Quantify impacts of waterborne methylmercury concentrations on key aquatic species, with emphasis on early life stages.
  - Determine interaction of methylmercury with other chemical and non-chemical stressors and investigate how these multiple stressors impact wildlife.

16

19

22

Results of this research will allow for a sensitivity analysis to prioritize areas that reduce uncertainty in the ecologic risk assessment. The results will contribute to improved assessments of mercury risk to wildlife and other ecological receptors.

### 3.1.2 Mercury Transport, Transformation and Fate

25

28

The ORD research program will improve information on the transport, transformation, and fate of mercury in the environment. The key scientific question and planned research area is:

31

**Key Scientific Question #3 (Transport, transformation, and fate):** *How much methylmercury in fish consumed by the U.S. population is contributed by U.S. emissions relative to other sources of mercury (such as natural sources, emissions from sources in other countries, and re-emissions from the global pool); how much and over what time period, will levels of methylmercury in fish in the U.S. decrease because of reductions in environmental releases from United States sources?*

- 34
- Upgrade multi-pollutant air modeling system to include the major speciated forms of mercury.
  - Reduce uncertainties in cloud chemistry and dry deposition of reactive gaseous mercury (i.e., HgCl<sub>2</sub>).
  - Determine the atmospheric chemistry and fate of the major speciated forms of mercury in the Arctic and Antarctic.
  - Understand the environmental cycling of the major speciated forms of mercury, especially the characteristics that induce mercury methylation in ecosystems and the pathways of exposure.
  - Obtain data on the spatial and temporal distribution of mercury deposition through a coordinated



1 monitoring program.

4 Results from this research will provide an improved understanding of the environmental fate and transport of mercury  
7 that will allow the Agency to further quantify how levels of methylmercury in fish will be affected by reductions in  
United States sources or how much of this methylmercury is contributed by U.S. emissions rather than by other  
sources of mercury (such as natural sources and re-emissions from the global pool). This issue is critical to  
establishing cost-effective controls on mercury by helping identify the sources most impacting a particular ecosystem.

### 10 3.1.3 Human Exposure to Methylmercury through the Aquatic Food Chain

13 The ORD research program will improve information on the actual levels of methylmercury to which humans  
and wildlife are exposed. The key scientific question and planned research area is:

16 **Key Scientific Question #4 (Human Exposure):** *How much methylmercury are humans exposed to, particularly,  
what are the exposures of women of child-bearing age and children among highly-exposed population groups; what  
is the magnitude of uncertainty and variability of mercury and methylmercury toxicokinetics in children?*

- 19  Analyze dietary survey data from surveys that are nationally representative as well as data from  
limited geographic regions, to assess exposures from fish and marine mammals to methylmercury.
- 22  Establish kinetic patterns of methylmercury distribution in children following ingestion of  
methylmercury from dietary sources.

25 Results from this research will provide a better understanding of the size of the population at risk. Taken together  
with emissions and fate and transport information, it will help to clarify the linkages among the concentration of  
methylmercury in fish, levels of ambient mercury in the environment, and source emissions. EPA Program Offices  
and other stakeholders (States, international community) will incorporate this information into future risk assessments  
28 and will also apply the results to identify source categories where reductions have had, or will have, the greatest  
impact on risk reduction.

### 31 3.1.4 Risk Management of Mercury and Methylmercury

34 The ORD research program will provide information on techniques that can be used to manage any adverse  
mercury and methylmercury risks and inform the public about those risks. The key scientific questions and planned  
research areas are:

37 **Key Scientific Question #5 (Risk Management for Combustion Sources):** *How much can mercury emissions  
from coal-fired utility boilers and other combustion systems be reduced with innovative mercury control technologies;  
what is the relative performance and cost of these new approaches compared to currently available technologies?*

- 40  Evaluate and field test manual and continuous emission monitors for measuring mercury in flue and  
stack gases, including those that can differentiate among the forms of mercury.
- 43  Determine how fuel or waste properties and combustion conditions (temperatures, residence times,  
quench rates, flue-gas composition, fly-ash-particulate properties and sorbent properties) affect  
46 the species of mercury in combustion systems.
- 49  Evaluate fundamental mechanisms of mercury capture and optimize methods for capturing mercury  
from flue gas, including techniques that get mercury in a form that is easier to control.

- 1            Investigate and determine the performance of mercury control technologies, including advanced low-cost sorbents and reagents capable of capturing mercury and other pollutants (e.g., sulfur oxides, nitrogen oxides, acid gases).
- 4            Estimate the capital and operating costs of various mercury control options.
- 7            Characterize the stability (leachability and volatility) of air pollution control device mercury residuals and evaluate any necessary options to stabilize these residuals.

10    ***Key Scientific Question #6 (Risk Management for Non-combustion Sources):*** *What is the magnitude of contributions of mercury releases from non-combustion sources; how can the most significant releases be minimized?*

- 13            Investigate ways to reduce the use of mercury in processes and products.
- 16            Investigate non-combustion alternatives to incineration and retorting of mercury-bearing hazardous waste.
- 19            Improve techniques to characterize fugitive emissions from industries, particularly chlor-alkali plants.
- 22            Evaluate sediment remediation methods, including those that interrupt the methylation process.
- 25            Quantify mercury emissions and releases from landfills.
- 28            Assess the relative importance of mining/processing wastes compared to other sources of mercury, and develop improved control techniques.

31    ***Key Scientific Question #7 (Risk Communication):*** *How does EPA effectively inform members of susceptible sub-populations of the health risks posed by mercury and methylmercury contamination of fish and seafood?*

- 34            Understand how people use risk information to make decisions about their methylmercury exposure.
- 37            Develop risk messages aimed at specific sub-populations (e.g., women of child bearing age).

40    Results of this research will provide improved emissions information and data on the cost and performance of control technologies and prevention options for priority source categories. OAR, OW, OSWER, and other Program Offices will use the results to support development of regulations for sources where the Agency has a statutory responsibility to address mercury releases. The results will also help States, Regions, and the private sector determine how specific technologies or prevention approaches can be used to meet emissions standards or voluntary reduction targets that have been negotiated with EPA and the international community.

46    The seven key scientific questions above provide the framework within which ORD will plan specific in-house research activities and develop requests for proposals from external organizations.

**3.2 CRITERIA FOR PRIORITIZING RESEARCH AREAS**

49    ORD selected the four criteria below to sharpen its focus for the *Mercury Research Strategy* and the subsequent implementation plan. The plan gives priority to areas that:

- 1 ✓ Support the goals and objectives of ORD's Strategic Plan, which include research and  
4 development to identify, understand, and solve current and future environmental  
problems;
- 7 ✓ Provide timely scientific information and data needed to inform current and future Agency  
decisions on mercury;
- 10 ✓ Fill data and information gaps not addressed by other organizations; and
- 13 ✓ Can be conducted or managed by ORD personnel with the appropriate technical  
expertise.

16 The first criterion flows directly from ORD's strategic plan (EPA, 1996), which is grounded in the risk paradigm . The  
second criterion is ORD's commitment to the Program Offices and Regions to provide them with sound scientific  
information and technical data so as to further the achievement of the Agency's mission and strategic goals. In the  
19 case of the third criterion, where scientific information and technical data are being developed by another organization  
(e.g., U.S. Geological Survey -- USGS, Department of Energy -- DOE), EPA will seek to work collaboratively with  
these organizations to convey their information and data to the appropriate Agency decision-makers (refer to Chapter  
5.0). The focus will be on work that complements ORD's efforts and is critical to fully answering the seven key  
22 scientific questions presented above. In the case of the fourth criterion, where ORD has limited capabilities and the  
broader research community (e.g., academic institutions, research foundations) is better equipped to conduct the  
specific research needed, ORD will solicit proposals through its STAR (Science to Achieve Results) Grants Program  
to develop scientific information and technical data.

### 25 3.3 SETTING PRIORITIES FOR MERCURY RESEARCH

28 Mercury is a human and wildlife problem and a high priority both within and outside the Agency.  
Consequently, internal stakeholders (e.g., Program Offices, Regions) and external stakeholders (e.g., regulated  
31 entities, environmental groups, community decision-makers at all levels, the general public, international entities)  
have an interest in the *Mercury Research Strategy* and its priorities. Stakeholders are particularly interested in  
research program sequencing and timing in order to determine whether it is consistent with their needs, interests, and  
(for the Agency) mandated deadlines (Table 3.). The *Mercury Research Strategy* is designed to provide broad  
34 direction for ORD's research program for mercury over the next five years. It is not intended to convey information on  
specific projects or provide a detailed schedule. Specifics will be presented in a subsequent ORD mercury  
implementation plan. What appears below is ORD's current sense of emphases for the mercury research program  
37 from FY 2000 through FY 2004. General resource projections for the seven key scientific questions presented in  
Figure 3 are consistent with the research strategy priorities. These projections are ORD's best judgment as of the  
preparation of the *Mercury Research Strategy*. The further into the future the projections go (e.g., FY 2003 -2004),  
40 the more qualitative they become. The rationale for emphasis trends for each of the key scientific questions follows:

#### 43 3.3.1 Human Health

46 Because an NAS report on the health effects of methylmercury is expected to be finalized in FY 2000, there  
will be a need to analyze and interpret the report and derive an Agency position on risk assessment for mercury. This  
will be critical to the revised human health water quality criterion for mercury planned for FY 2000 and to the  
regulatory determination on mercury controls for utilities planned for FY 2001. If the Agency determines to regulate  
49 utilities for mercury, continued support in health assessment will be needed through that time. The National Center  
for Environmental Assessment (NCEA) has the capability to conduct such a risk assessment and will lead the effort.

1 **3.3.2 Ecological Systems**

4 Effects of methylmercury have been demonstrated in ecological systems and there is a need to learn more  
about methylmercury's effects on these systems, particularly its effect on wildlife. This research will assist in the  
development of mercury criteria for wildlife. Health assessment needs in support of the Total Maximum Daily Load  
(TMDL)<sup>6</sup> will predominate in FY2000 but will be replaced by a growing need for ecological research in later years.  
7 This ecological research will be split approximately evenly between effects and assessment research. Expertise is  
available within ORD for both types of research (NCEA and National Health and Environmental Effects Research  
Laboratory -- NHEERL), but research being conducted by other federal organizations and projects under the STAR  
10 Grants Program will also contribute.

13 **3.3.3 Fate and Transport**

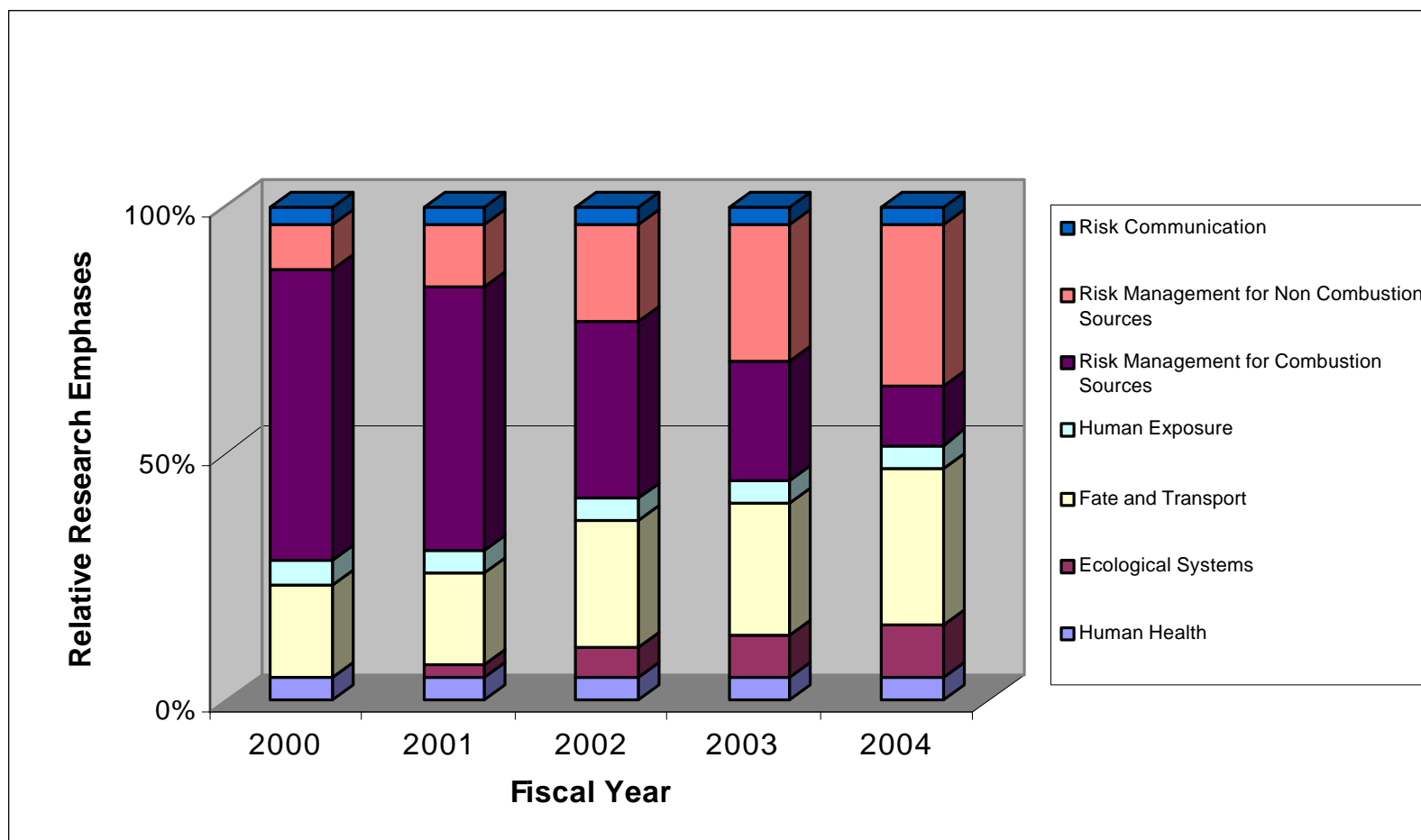
Fate and transport research on mercury will increase through the FY 2000-2004 period. Answers will take  
some time to develop because the fate and transport of mercury is complex. This research is considered a high  
16 priority for understanding the problems posed by mercury releases to the environment. Research will increase  
through the 2000-2004 time period to allow a better understanding of this issue for future regulatory efforts on  
mercury. Expertise in ORD is available in the National Exposure Research Laboratory (NERL), but will be  
19 supplemented by projects under the STAR Grants Program..

22 **3.3.4 Human Exposure**

The critical pathway for exposure to mercury in humans and wildlife is via methylmercury-contaminated fish.  
Thus, monitoring of methylmercury in fish and support for improving estimates of fish consumption are important in  
25 understanding exposure. This is expected to be a level effort throughout the FY 2000-20004 time frame. This  
research will likely be conducted under contracts or cooperative agreements monitored by ORD scientists in NCEA  
and NERL.  
28

---

<sup>6</sup> A TMDL is developed for a water body if water quality standards within the body are not being met using  
technology-based or other effluent controls. It establishes the maximum allowable pollutant loading for a water body (including  
allocations for point and non-point source loads and a margin of safety) that will result in compliance with established water  
quality standards (EPA, 1999c).



1  
4  
7  
10  
13  
16  
19  
22  
25  
28  
31  
34  
37  
40  
43  
46  
49

**3.3.5 Risk Management for Combustion Sources**

This research addresses the highest short-term mercury need and will require the largest proportion of the research budget in FY 2000 and 2001. Requirements for this research will decrease, however, over the FY 2002-2004 time period with a concomitant increase in support for research addressing ecological systems, fate and transport, risk management for non-combustion sources. The risk management research for combustion sources supports the Agency's regulatory determination for mercury control in utilities, which will have to be made by FY 2001. EPA's National Risk Management Research Laboratory (NRMRL) has the facilities and expertise to conduct this research and is working with other Federal agencies, including the Department of Energy (DOE) and the public and private sectors (e.g., the Electric Power Research Institute [EPRI]), to demonstrate the most promising risk management technologies for mercury management.

**3.3.6 Risk Management for Non-Combustion Sources**

Research in this area will be modest in FY 2000 but will increase over the FY 2000-2004 period as the need for risk management research for utilities decreases. The research will address mercury-producing sources such as chlor-alkali plants and gold mining. Rulemaking for non-combustion sources is expected to occur following that for utilities. Expertise in development of control technology for non-utility sources of mercury and methylmercury is again available in NRMRL, but other Federal organizations (e.g., USGS) and institutions involved in mercury and methylmercury risk management for non-combustion sources will also be engaged.

**3.3.7 Risk Communication**

Research to improve risk communication to populations at risk of elevated exposures to methylmercury from fish will remain constant over the 2000-2004 period. Communication approaches will need to be developed that address risks specific to those who have high levels of fish consumption (e.g., persons of Native American and Asian ethnicity) and those who are at heightened risk because of vulnerability of the nervous system (e.g., maternal/fetal pair, nursing mother/infant pair, and young children). NCEA will be responsible for this effort and will use both contracts and cooperative agreements in its undertaking. NRMRL is also available to provide research and support on technical information transfer vehicles and venues as part of ORD's efforts in stakeholder engagement.

The seven key scientific questions in the *Mercury Research Strategy* will meet domestic regulatory commitments and offer international opportunities for addressing mercury. Pressing policy and legislative issues also drive ORD's human health and environmental research priorities. While the *Mercury Research Strategy* remains grounded in the risk management paradigm, satisfying Program Office and Regional research needs over the next several years is central to its success; ORD plans to focus on those research needs in the near term. In the longer term, research that enhances the fundamental understanding of mercury fate and transport, human health exposure and effects, wildlife effects, and non-combustion risk management will be emphasized. Research on communicating the risks of methylmercury exposure to those individuals and groups at greatest exposure will be an ongoing effort.

**3.4 RESEARCH AND INFORMATION GATHERING BY OTHER ORGANIZATIONS**

Mercury has affected humans for centuries. The current interest in mercury and its impacts on human health began with the outbreak of methylmercury poisonings in Minamata Bay, Japan, more than 50 years ago (EPA, 1997a). Since then, a wide range of scientific and technical investigations by a variety of interested parties have advanced the worldwide understanding of the human health impacts of acute and chronic exposures to methylmercury. This understanding has been extended over the years to fundamental insights on sources, routes, wildlife effects and, to a lesser degree, risk management of mercury and methylmercury. A thorough treatment of

1 EPA's knowledge on the subject of mercury is presented in the *Mercury Study Report to Congress*; however, as  
posed in this research strategy, there are still questions needing to be answered.

4 ORD, by its very design and focus on the risk management paradigm, is uniquely positioned to lead an  
integrated research program on risk assessment and risk management of mercury and methylmercury; however, the  
research proposed in this strategy cannot be accomplished by ORD alone. ORD must have the help of other public  
7 and private organizations (e.g., Federal, State, and local governments, academic institutions, private sector) in  
addressing the key scientific questions. Research by EPA must be undertaken in concert with other organizations  
conducting research in areas of common interest and endeavor. While it is not the intent of the *Mercury Research*  
10 *Strategy* to present a comprehensive description of past or current mercury research, it is important that  
organizations involved in scientific and technical investigations and information gathering related to mercury be  
identified. Once identified, EPA can collaborate with them to enhance the results and better achieve the goal of this  
13 research strategy. Below is a brief summary of organizations and their contributions to improving the scientific and  
technical understanding of mercury on the basis of the four research categories identified in Chapter 3.1. Again, this  
is not an exhaustive discussion, but indicative of the organizations and their major efforts currently underway that will  
16 assist in achieving the goal of the *Mercury Research Strategy*.

### 19 **3.4.1 Human Health and Wildlife Effects of Methylmercury**

*Human Health:* The National Institutes of Health (NIH) and the National Institute for Environmental Health Sciences  
(NIEHS) have been investigating the adverse human health effects of methylmercury for a number of years.  
22 Investigations are addressing the mechanisms of action of methylmercury on the nervous system and evaluating its  
effects on other systems (e.g., endocrine, immune). Government agencies in other countries (e.g., Denmark,  
Germany, France) are also identifying adverse human health effects of methylmercury and investigating mechanisms  
25 of action on the nervous system. Assessments are also being conducted in other countries to describe the dose-  
response analyses and set the No Observed Adverse Effects Levels (NOAELs) and the Lowest Observed Adverse  
Effect Levels (LOAELs)

*Ecological Systems:* The USGS and the U.S. Fish and Wildlife Service (USFWS) have active research programs to  
evaluate the mechanisms of methylmercury bioaccumulation in fish and wildlife species. One program correlates  
31 mercury concentrations in sediment, water, and fish at 100 sites nationally with water and sediment parameters.  
Determining the role of sediment microbial communities in the methylation of mercury is another important program.  
Much of the research is associated with regional assessments, such as the Great Lakes or the South Florida  
34 Everglades programs. Many States conduct fish surveys to assess tissue concentration. DOE's Oak Ridge National  
Laboratory scientists have conducted risk assessments to determine the impacts of site-specific mercury  
contamination on fish and avian species.

### 37 **3.4.2 Mercury Transport, Transformation and Fate**

*Transport, transformation, and fate:* The National Oceanic and Atmospheric Administration's (NOAA) Atmospheric  
Research Laboratory (ARL) also develops numerical simulation models for atmospheric mercury and other air toxics.  
ARL has thus far been focused on Lagrangian-type numerical frameworks (i.e., HYSPLIT), not the 3-d fixed grids  
43 with high-resolution nesting and complex chemistry like EPA's Models-3/CMAQ. The National Exposure Research  
Laboratory's Atmospheric Modeling Division is, in fact, a Division of NOAA's ARL that has been assigned to work for  
EPA's Office of Research and Development, and reports to the Director of ARL, so there is close coordination among  
46 EPA and NOAA's research activities. Aquatic and Terrestrial Transport, Transformation and Fate: The U.S.  
Geological Survey (USGS) also conducts research in aquatic and terrestrial transport transformation and fate of  
mercury. ORD has worked closely with the USGS in the establishment of a coordinated research program for the  
49 investigation of ecological processes in the field and the collection of environmental data for model development and

1 validation, particularly in studies related to the restoration of the South Florida Ecosystem, and has developed  
long-term professional relationships with many USGS scientists involved in mercury research.

### 4 **3.4.3 Human Exposure to Methylmercury Through the Aquatic Food Chain**

7 *Human Exposure:* The National Center for Health Statistics (NCHS) collects biomonitoring data on mercury  
concentrations in hair and blood of examinees in the National Health and Nutrition Examination Survey (NHANES) IV.  
This survey provides information on the distribution of mercury exposures in the general United States population, but  
does not provide information on specific sub-populations that may have higher than typical exposures. FDA monitors  
10 mercury levels in fish sold in interstate commerce. Many States have regular monitoring of mercury levels in game  
fish, used in setting fish consumption advisories.

### 13 **3.4.4 Risk Management of Mercury and Methylmercury**

16 *Risk Management for Combustion Sources:* ORD is working cooperatively with DOE's Fossil Energy Technology  
Center (FETC), USGS, and the Electric Power Research Institute (EPRI) to develop and evaluate improved mercury  
measurement methods and more cost-effective mercury emission reduction technologies. A team individuals from  
each organization is preparing a joint research strategy that will define roles and responsibilities, identify areas for  
19 collaboration, and coordinate the transfer of new information obtained through the research. DOE and EPRI are  
working collaboratively with EPA on mercury measurement methods. DOE and EPRI have the lead to evaluate both  
manual and continuous methods to measure mercury species from coal-fired boilers, while EPA will focus its attention  
22 on methods for incinerators and other non-fossil-fuel combustion sources, with some assistance from DOE's National  
Laboratories. Understanding the characteristics of different coals and the possibility of cleaning coal before it is  
burned are also important areas in which EPA is relying on other agencies and the private sector. DOE, USGS, and  
25 EPRI are working jointly with EPA's Office of Air Quality and Planning Standards and utilities to enhance knowledge  
about the mercury content of various coals. DOE and EPRI will conduct limited studies on the use of coal cleaning for  
reducing mercury emissions and have the lead to investigate using advanced coal cleaning techniques to control  
28 mercury emissions from coal-fired boilers. DOE and EPRI will also play a lead role in testing innovative control  
technologies, including multi-pollutant controls developed by ORD, in pilot- and full-scale utility boilers.

31 *Risk Management for Non-combustion Sources:* There are few other research programs on the characterization and  
management of mercury releases from non-combustion sources. In the Federal Government, DOE is the principal  
actor. DOE has a program to study non-thermal alternatives to mercury-bearing mixed wastes (including soils), and  
34 another to study alternatives to mercury use in fluorescent light bulbs. DOE is also conducting limited studies on  
landfill emissions and emissions measurement techniques. Voluntary efforts are under way in some industrial sectors  
to assess mercury use and releases. USGS continues to collect data on both consumption and production of mercury  
37 and has been conducting a program to address mercury releases from mining operations in the western United  
States. The Chlorine Institute is studying the fate of mercury in chlor-alkali plants that use the mercury cell process.  
The American Hospital Association is studying ways to reduce mercury use in hospitals.

40 *Risk Communication:* Risk communications on methylmercury have been almost exclusively tied to messages about  
methylmercury in fish. Communicating both the benefits of consuming fish and the accompanying risk of ingesting  
43 the contaminants often found in fish is a complex process. The 39 states that have fish advisory programs on  
mercury have risk communication programs that typically target sensitive sub-populations. The extent to which  
research on how these messages are tailored to ethnically diverse populations varies. Research on factors that  
46 complicate communication (e.g., prior beliefs and attitudes, silent questions and concerns) when addressing people  
of diverse ethnic backgrounds is also a critical component of successful communication of risk. A great deal of work  
in this area is either disease specific (e.g., transmission of HIV), behavior specific (e.g., smoking cigarettes) or agent  
49 specific (e.g., risks of exposure to lead or to radon). Funding sources for such work vary with the disease or agent.



1 Some general work on risk communication appears to have been sponsored by organizations such as the National  
Science Foundation and by the Chemical Manufacturers Association. State governments, private foundations, and  
various health agencies (e.g., Centers for Disease Control) conduct research on communicating risk of various  
4 diseases and injuries.

7 Based on the input received from the various research strategy writing teams, direct contacts with other  
Federal and private organizations, and a review of the literature (both hard copy and on-line), a number of  
organizations can make a contribution to the seven key scientific questions presented in Chapter 3.0. While EPA is  
currently collaborating with a number of these organizations on mercury research, such is not universally the case.  
10 As currently envisioned, the most effective vehicle for engagement of multiple Federal organizations is the Committee  
on the Environment and Natural Resources (CENR) under the White House Office of Science and Technology Policy  
(OSTP). This engagement is being undertaken with the delivery and request for review of the *Mercury Research*  
13 *Strategy* by the CENR. Once comments have been received from CENR members, official contact will be made with  
the appropriate organizations, and relationships, if not already ongoing (e.g., USGS, DOE, NIH), will be established.

16 In addition to research targeted at specific aspects of the mercury problem (e.g., human health,  
management of combustion sources), Federal organizations and others are conducting applied research and  
collecting scientific information that informs EPA's efforts on mercury. These efforts are by and large focused on  
19 particular geographic regions or locales where mercury has been identified as a problem. Examples include: (1) the  
National Estuary Program, administered by EPA's Office of Water – working to restore and enhance 28 nationally  
significant estuaries; (2) EPA's Great Waters Program -- charged to research and resolve environmental issues  
22 effecting the Great Waters of the United States (e.g., Great Lakes, Chesapeake Bay); (3) the National Estuarine  
Research Reserves System (NERRS), administered by the National Oceanic and Atmospheric Administration  
(NOAA) – conducting long-term research, education, and stewardship of 23 national estuarine reserves; and (4)  
25 EPA's South Florida Ecosystem Restoration Research Program – charged by Congress to study water quality and  
the environmental impacts of development on the Everglades. More thorough descriptions of several of these  
examples, and many others, are presented in the draft of the *Third Great Waters Report to Congress* on atmospheric  
28 deposition in the Great Waters (EPA, 1999c) and the draft of the *U.S. Status Report of Mercury Activities* prepared for  
the NACEC's NARAP on Mercury (EPA, 1999d). Other examples of large programs addressing mercury as one of  
31 their components are the CALFED Bay -- Delta Program addressing water quality in the San Francisco Bay and  
Sacramento - San Joaquin Delta Estuary watershed (CALFED, 1999) and the Arctic Research Program and  
associated draft *United States Arctic Research Plan* (NSF, 1999). All of these organizations should have an interest  
in, and can make a contribution to, advancing EPA's mercury research program.

## 4. KEY SCIENTIFIC QUESTIONS

Using the seven key scientific questions described in Chapter 3.0, the mercury writing teams developed the associated research areas and supporting descriptions of research needs presented below. These needs were then arranged in priority order for presentation under each key scientific question. The prioritization process was based on the four research area selection criteria described in Chapter 3.2. The relationships between each of the research areas described in this chapter and the EPA commitments in Chapter 2.0 are presented in Appendix 1.

### 4.1 HUMAN HEALTH

**4.1.1 Key Scientific Question #1:** *What critical changes in human health are associated with exposure to environmental sources of methylmercury in the most susceptible human sub-population?*

#### 4.1.1.1 Background.

The initial step in the risk assessment process is identification of health hazards. Earlier Reference Doses (RfDs) for methylmercury were based on neurological changes in the adult. In 1994 EPA announced a new RfD based on adverse effects of children's neurological development secondary to *in utero* exposures resulting from maternal consumption of methylmercury during pregnancy. Other Federal agencies (e.g., FDA) continued to base their regulatory activities on effects in adults or have developed draft assessments (e.g., ATSDR's Toxicology Profile on Mercury [ATSDR, 1999]) that were aimed at a fetal protective dose based on epidemiological studies of other populations. Since 1995 (and until 2000), deliberations have focused on the appropriateness of various epidemiological investigations for risk assessment. It is anticipated that this issue will be resolved before 2003 to 2005. Also, the FY 1999 Congressional budget contains a \$1.0M appropriation for the National Academy of Sciences (NAS) to conduct a study on the appropriate reference dose for methylmercury. This latter effort will involve a review of the health research on mercury conducted since the completion of the *Mercury Study Report to Congress*. The NAS study will assist the Agency in reevaluating the RfD for methylmercury with respect to human health impacts.

As part of the discussions on the risk characterization for methylmercury, it was determined that young children are exposed to higher doses of methylmercury than are adults (e.g., approximately 1.5- to 2-fold or higher on a body-weight basis) (EPA, 1997a). It was recognized that the postnatal nervous system remains vulnerable to methylmercury; however, it is uncertain whether the young child's sensitivity to neurological effects of methylmercury is more like that of the fetus or that of the adult. Children also appear to have different patterns of tissue distribution of mercury and methylmercury (i.e., biokinetic patterns) than do adults. For these reasons, determining the dose-response to postnatal mercury and methylmercury exposures among children is critical. Health effects research on the immunotoxicity of both inorganic mercury and methylmercury was conducted during the mid-1990s. This research raised concerns that immunological effects might occur at lower exposures than did neurological effects. As a consequence, the Agency set the current RfD for methylmercury at a dose thought to be protective against known adverse immunotoxicity effects.

#### 4.1.1.3 Program Relevance.

The practical importance of a separate pediatric RfD results from higher exposures (on a  $\mu\text{g}/\text{kgbw}/\text{day}$  basis) to methylmercury among children than among adults. If children are both vulnerable and more highly exposed relative to body weight than are adults, children rather than the maternal-fetal pair may be the subpopulation of greatest concern. Although the RfD for the young child may not be very different from an RfD that is protective of the fetus, policy statements would need to address the much higher intake (on a  $\mu\text{g}/\text{kg}$  by weight basis) of the young

1 child. If research subsequently demonstrates that immunotoxicity occurs at lower doses of mercury than do neuro-  
developmental and neuro-behavioral changes, it may be necessary to revise the RfD to protect against  
immunotoxicity.

#### 4 4.1.1.3 Prioritized Research Needs.

7 *Understanding mechanisms of developmental neurotoxicity.* While methylmercury is a well-recognized  
developmental neurotoxicant in humans and animals, the critical mechanism(s) are still ill-defined. An improved  
10 understanding of the mechanisms of methylmercury's developmental neurotoxicity should be linked to exposure data  
in the form of biokinetic models, in order to provide an improved framework for the design of biologically based dose-  
13 response (BBDR) models. These models would need to include reliable predictions of adverse effects following  
prenatal, postnatal, and perinatal exposure scenarios. Improved understanding of mechanisms of developmental  
16 neurotoxicity following exposure to mercury and methylmercury could greatly enhance interspecies extrapolation in  
the risk assessment of this environmentally persistent pollutant. It is necessary to understand and characterize  
children's risk because no readily available population exists for postnatal-only exposures. Mechanistic modeling of  
19 methylmercury-induced developmental neurotoxicity is predicated on the current and continuing research both in  
humans, *in vivo* animal models, and *in vitro* models where exposure and effects have been determined. This research  
22 provides the unique opportunity to expand understanding beyond theoretical models based upon developmental  
mechanisms of action for experimental data, and provide some predictability of effects following actual low-level  
25 exposures in developing humans. Mechanistic understanding for methylmercury's developmental neurotoxicity has  
significant implications for other compounds and should help to define what developmental processes, endpoints, and  
time points may be especially sensitive to developmental perturbation. In addition, experimental evidence suggests  
that the effects of mercury and methylmercury exposure on the development of the nervous system and immune  
system may involve some common mechanisms (neurotrophic factors and cytokines).

28 *Risk assessment uncertainties due to compensation.* In addition to improving our mechanistic understanding of the  
pathogenetic processes that lead to altered function following mercury and methylmercury exposure, an improved  
understanding of compensatory mechanisms that incorporate pharmacokinetic and pharmacodynamic factors could  
31 greatly reduce uncertainty in risk assessment for human health effects. Currently, the consequences of transient  
functional and morphological changes following developmental insults in animals make it difficult to predict if a given  
exposure level will have long-term or persistent adverse effects in humans. This difficulty arises from the degree of  
34 compensation that occurs following developmental insults before a threshold of detection is reached, and the  
uncertainty that compensation is categorically a good thing. This issue also leads to increased uncertainty in the risk  
assessment process. Recent data suggest that neural compensation may come at a cost to the organism later in life,  
37 with diminution of both structural and functional capacity. This may have significant implications for subsequent  
exposures to other xenobiotics, or it may reveal itself functionally or clinically later in life with premature senescence  
(i.e., accelerated aging). Anecdotal data from humans and experimental data from animal studies indicate that  
40 mercury may result in accelerated aging. Increased understanding of these underlying biological processes has  
significant potential in informing the scientific and regulatory community about the nature of children's risk during  
prenatal, postnatal, and perinatal exposures by helping to characterize the limits of compensation following  
developmental damage to the nervous system.

43 *Risk assessment uncertainties following aggregate exposure to developmental neurotoxins.* An improved  
mechanistic understanding of the developmental neurotoxicity of methylmercury will also assist in the determination of  
46 additive, subtractive, and synergistic relationships among other commonly occurring environmental pollutants (e.g.,  
dioxin, PCBs, dibenzofurans). Human epidemiological data are often complicated by exposure to a combination of  
many pollutants (e.g., Great Lakes fish and marine mammals; fish of the North Sea), and more research is needed to  
49 characterize the neurotoxicity and immunotoxicity of aggregate exposures.

1 *Understanding Immunotoxicology of Mercury and Methylmercury.* Recent data suggest that exposure to mercury  
compounds through a number of routes can modulate immune responses. Immunomodulation is manifested as an  
adverse effect in three general areas: autoimmunity, immune suppression (with enhanced risk for infectious disease),  
4 and allergy. Specific research findings in these areas include:

7 **!** *Autoimmunity.* Mercury exposure in either experimental animal models or in humans has been shown to be  
a potent stimulus for the expression of autoantibodies and autoimmune responses in some susceptible  
populations. The risk for latent autoimmune diseases following low-level developmental exposure of children  
is largely unknown.

10 **!** *Immune Suppression.* Methylmercury has been reported to be a potent effector of immune suppression,  
including both humoral responses and natural killer cell activity. Humoral response consists of antibody  
13 production; natural killer cell activity protects against infectious agents. The subsequent effects of  
developmental exposure, at least in experimental animals, indicate that there is an increased risk, principally  
during the postnatal period, leading to increases in the number and severity of infections later in life.

16 **!** *Allergy.* Exposure to either organic or elemental mercury is a well-known environmental stimulus of  
allergic responses (i.e., contact dermatitis) in humans and animals. These responses have been  
19 demonstrated in adults and children. There is, however, little clear evidence to date of age-related sensitivity  
either qualitatively or quantitatively.

22 These findings raise the following questions:

25 How does developmental exposure to methylmercury affect immune responses and susceptibility to disease? What  
components of the immune system are affected? Is there a critical window of opportunity? What are the dose-  
response relationships? What are the underlying mechanisms? How do answers to these questions compare to  
developmental neurotoxicity, another critical effect?

28 Susceptibility to immunotoxic effects may differ substantially across sub-populations. Factors that  
predispose the organism to autoimmunity and/or allergic responses are not well characterized in humans. WHO  
31 (1991) concluded, based on animal studies, that the most sensitive adverse effect for inorganic mercury risk  
assessments is the formation of mercury-induced autoimmune glomerulonephritis. Understanding dose-response  
among sub-populations that are particularly sensitive to the immunotoxic effects of mercury is limited, it is not  
34 scientifically possible to set a level of exposure below which mercury-related symptoms will not occur. This  
observation raises research questions, including the following:

37 What is the magnitude of the risk of autoimmune disease associated with exposure to inorganic mercury? What is  
the dose-response relationships? Are there sensitive populations, is the developing immune system particularly  
vulnerable? How can we link experimental animal research and epidemiology studies to improve the risk assessment  
40 process?

#### 43 4.1.2 Measures of Success

Researchers hope to obtain the following:

- 46 • A sufficient understanding of biokinetics of mercury and methylmercury in young children to permit  
interpretation of monitoring and modeling data from various ongoing research projects.
- 49 • An improved determination as to whether young children or maternal-fetal pairs are the

1 subpopulation at greatest risk from methylmercury exposures.

- 4 • An improved determination as to whether immunological toxicity or neurotoxicity are most important at the lower exposure.

## 7 4.2 ECOLOGICAL SYSTEMS

### 10 4.2.1 Key Scientific Question #2: *What are the risks associated with methylmercury exposure to valued wildlife species and other significant ecological receptors?*

#### 13 4.2.1.1 Background.

16 Recent scientific progress has led to a greatly improved understanding of mercury fate and transport in the environment and its toxicity to a wide range of ecological receptors. This work has focused attention on the aquatic environment and, in particular, on consumption of methylmercury-contaminated fish by piscivorous birds and mammals. A review of this material is provided in "An Ecological Assessment for Anthropogenic Mercury Emissions in the United States," Volume VI of the *Mercury Study Report to Congress* (1997a). The report primarily assessed the impacts of mercury and methylmercury on wildlife and did not focus on fish or other biota.

22 Despite this progress, however, substantial scientific uncertainties remain that limit efforts to characterize the ecological risks associated with anthropogenic mercury emissions. The research areas prioritized below reflect EPA's need to assess the risk of methylmercury to piscivorous wildlife and to calculate water-based wildlife criteria for mercury that are protective of piscivorous wildlife populations. The Agency recognizes that this prioritization could change substantially as new information about mercury exposure and effects becomes available. It is also recognized that in many cases it is difficult, and sometimes counterproductive, to consider chemical effects apart from exposure. While the emphasis of this effort is on research needs for ecological effects assessments, the reader will recognize several specific suggestions that incorporate an exposure assessment "component."

#### 31 4.2.1.2 Program Relevance.

34 Mercury pollution of aquatic systems is a national problem. In June 1999, fish consumption advisories due to unacceptable levels of mercury exist in 39 States. In some cases, these advisories can be traced to point sources of mercury. Increasingly, however, non-point source mercury contamination has resulted in large-scale pollution of entire ecosystems, with possible impacts on both humans and wildlife. Perhaps the best known example is that of the South Florida Everglades, which is home to the endangered Florida panther. High levels of mercury and methylmercury in tissues of deceased animals have led to the suggestion that methylmercury is a contributing factor in the decline of the panther population. It is the responsibility of EPA's Regional Offices to deal with such problems. Seeking technical assistance, the Regions have engaged the Office of Research and Development (ORD), the Office of Water (OW), the Office of Air Quality Planning and Standards (OAQPS), and others, to address this concern.

43 EPA has the responsibility under the Clean Water Act (Section 304(a)(1)) to develop water quality criteria that are protective of wildlife that may be exposed to chemical pollutants in water. The first effort to develop a wildlife criterion for mercury was undertaken by OW in support of the Great Lakes Water Quality Initiative (GLI). The GLI was promulgated as a rule, and as such, constitutes a powerful legal mandate. States in the Great Lakes basin have either submitted or are drafting strategies for compliance with the GLI. EPA Regions (Regions II, III, and V) that adjoin one or more of the Great Lakes are primarily responsible for implementation of the GLI, including the wildlife criteria for mercury. Uncertainties regarding wildlife exposures to methylmercury and the subsequent effects of those exposures have greatly complicated these efforts. This research initiative will serve to strengthen scientific credibility

1 of water quality criteria for mercury and procedures for implementing those criteria in watersheds throughout the  
Nation.

#### 4 4.2.1.3 Prioritized Research Needs.

7 The major research needs are identified below in order of their relative priority. Each is accompanied by a  
brief narrative, the intent of which is to describe the type of work that would be required to address these needs.

10 *Toxicity of methylmercury to avian and mammalian wildlife.* A need exists for controlled laboratory studies of  
methylmercury disposition and effects in wildlife species or appropriate surrogates. Current procedures for  
13 calculation of a wildlife criterion (WC) for mercury are based on an extremely limited toxicity data set. Moreover, in  
the calculation of a wildlife RfD for methylmercury, there is a need to use several uncertainty factors (e.g., species-to-  
species, LOAEL-to-NOAEL), each of which is supported by only very limited data. Research should be conducted to  
16 characterize the kinetics of methylmercury uptake and disposition, and the importance of hepatic demethylation as a  
route of elimination. Additional research is needed to develop and refine assessments of risk based on mercury and  
methylmercury residues in the tissues of exposed wildlife and their prey. Tissue residue-based assessments have  
the potential to avoid many uncertainties associated with assessing mercury and methylmercury exposure. However,  
19 research is needed to support the development of reliable tissue-residue response relationships, including:  
identification of critical target tissues, assessment of interspecies and intraspecies differences in sensitivity; and the  
development of Physiologically-Based Pharmacokinetics (PBPK) dosimetry models for sensitive and/or highly  
exposed species.

22 *Wildlife Risk Assessment Methods.* The research above will contribute to improved assessments of mercury risk to  
wildlife and other ecological receptors. It is possible, however, to identify research that focuses directly on the risk  
25 assessment process as a means of addressing specific problems. Given the relatively small number of avian and  
mammalian wildlife species that prey heavily on fish, it is reasonable to collect species-specific information that would  
lead to improved exposure characterizations. This would include characterizations of exposure variability due to  
28 seasonal changes in location and dietary choice. In risk characterization, probabilistic and distributional methods  
must be applied to both exposure and effects information. Analyzing the distribution or range of a given parameter  
(i.e., toxic effects, fish size, food consumption) will reduce uncertainty. For example, point estimates of effect could be  
31 replaced by information that would permit the calculation of effects benchmarks and statistical confidence limits.

34 Revising laboratory experimental designs to produce dose-response curves with EC10, EC20, etc., values  
will enhance the use of probabilistic methods. Existing ecological risk assessment methods are, in general, poorly  
adapted for use with compounds that bioaccumulate and are biotransformed. New assessment methods must be  
37 developed to accommodate these factors, perhaps in concert with more site-specific and/or residue-based regulatory  
procedures. It is expected that future exposure research efforts will be focused on identification of aquatic systems  
that have characteristics for significant methylmercury production. This work should be complemented by research  
on other factors that contribute to variability in bioaccumulation of methylmercury by fish. Bioenergetics-based  
40 bioaccumulation models for fish must be developed to provide probabilistic residue estimates within and among  
trophic levels.

43 *Ecological impacts of methylmercury on avian and mammalian wildlife.* Using a "weight of evidence" approach, the  
authors of the Report to Congress reached the conclusion that mercury originating from airborne sources has had an  
adverse impact on several avian and mammalian wildlife species. Field data required to confirm or refute this  
46 suggestion are, however, lacking. A need exists to conduct field research on wildlife species. This research would  
be complementary to the laboratory studies described previously. Critical questions that would be addressed by this  
work include: (1) Are there species that, because they possess specific attributes, could function as sentinels for  
49 mercury contamination? (2) Do field data support projections of increased risk to wildlife living in proximity to mercury

1 emissions sources? and, (3) Can population attributes (e.g., age-class structure) be used to indicate adverse effects  
on individuals? A critical question for establishing a WC value for mercury is whether a population of animals can  
withstand adverse effects on a limited number of individuals. Population models for relevant species must be  
4 developed to predict the probability of localized extinction due to impacts on critical population parameters (e.g.,  
reduction in the per capita growth rate due to reproductive effects), as well as time-to-recovery under different  
exposure reduction scenarios. Finally, it is important to determine whether sublethal exposures to methylmercury can  
7 contribute to the demise of endangered wildlife species.

10 *Impacts on fish and other non-avian, non-mammalian ecological receptors.* Based largely upon exposure  
considerations, it may be concluded that piscivorous avian and mammalian wildlife species are most at risk to  
adverse effects of environmental mercury. This analysis presumes, however, that the toxicological sensitivity of all  
animals to mercury (on a delivered dose basis) is approximately the same. The possibility exists that there are  
13 animals that, because of increased sensitivity, experience adverse toxic impacts at relatively lower tissue-residue  
burdens. Research focused on early life stages of fish has revealed toxic impacts at waterborne methylmercury  
concentrations previously thought to have no effect on fish. This work should be expanded and similar research  
16 conducted on other key aquatic species. Additional work is also needed to evaluate mercury and methylmercury  
toxicity to some terrestrial species, especially those that inhabit forest soils and soil drainages. A second possibility  
is that there are non-wildlife aquatic or terrestrial species that, because of unusual bioaccumulation and/or food web  
19 relationships, experience mercury exposure comparable to that of piscivorous wildlife.

22 *Multiple Stressor Interactions.* Mercury often co-occurs with other chemical stressors, and in particular with  
compounds that tend to bioaccumulate in aquatic biota, including polychlorinated biphenyls (PCBs) and 2,3,7,8-  
tetrachlorodibenzo-p-dioxin (TCDD). In mixture studies with mink, methylmercury, and PCBs acted together,  
resulting in toxic effects greater than those that could be attributed to either chemical individually. Additional studies  
25 of this type are needed to define the nature of these chemical interactions. Field research is also required to  
investigate the potentially modifying effects of both chemical and non-chemical stressors. Perhaps the best example  
to date is that of the Florida panther. While it can be shown that mercury residues in dead panthers exceed levels  
28 found in experimentally intoxicated cats, a multitude of other factors complicate any assessment of risk. Included  
among these factors are habitat fragmentation and a lack of genetic diversity.

#### 31 **4.2.2 Measures of Success**

34 Researchers hope to obtain the following:

- 37 • Successful characterization of the toxicokinetics and toxicodynamics of methylmercury in  
piscivorous avian and mammalian wildlife.
- 40 • Development of probabilistic ecological impact assessment procedures for mercury that explicitly  
recognize relevant natural processes.
- 43 • Characterization of the impact of methylmercury on piscivorous wildlife populations at local,  
regional, and national scales.
- 46 • Reduction in the uncertainty in evaluation of potential adverse effects on fish.
- 49 • Evaluation of the potential for adverse impacts on fish and other non-avian, non-mammalian  
ecological receptors.
- Identification and characterization of important interactions of mercury with other environmental

1 stressors.

### 4 4.3 FATE AND TRANSPORT

7 **4.3.1 Key Scientific Question #3:** *How much methylmercury in fish consumed by the U.S. population is contributed*  
10 *by U.S. emissions relative to other sources of mercury (such as natural sources,*  
13 *emissions from sources in other countries, and re-emissions from the global*  
16 *pool); how much and over what time period, will levels of methylmercury in fish in*  
19 *the U.S. decrease due to reductions in environmental releases from United*  
22 *States sources?*

#### 13 4.3.1.1 Background.

16 Mercury bioaccumulates most efficiently in the aquatic food web. Predatory organisms at the top of the food  
19 web generally have higher methylmercury concentrations. Nearly all of the mercury that accumulates in fish tissue is  
22 methylmercury. Inorganic mercury, which is less efficiently absorbed and more readily eliminated from the body than  
25 methylmercury, does not tend to bioaccumulate. Fish consumption dominates the pathway for human and wildlife  
28 exposure to methylmercury. The *Mercury Study Report to Congress* supports a plausible link between anthropogenic  
releases of mercury from industrial and combustion sources in the United States and methylmercury in fish.  
However, these fish methylmercury concentrations may also result from existing background concentrations (which  
may consist of mercury from natural sources, as well as mercury that has been re-emitted from previous  
anthropogenic activity) and deposition from the global reservoir (which includes mercury emitted by other countries).  
Given the current scientific understanding of the environmental fate and transport of this element, it is not possible to  
quantify how much, and over what time period, levels of methylmercury in U.S. fish will be reduced by reductions in  
environmental releases from U.S. sources, or how much of the methylmercury in fish consumed by the U.S.  
population is contributed by U.S. emissions relative to other sources (such as natural sources and re-emissions from  
the global pool). As a result, decision makers do not have quantitative information to relate potential reductions in  
environmental releases to reductions in exposure. This is a high-priority area for research.

#### 31 4.3.1.2 Program Relevance.

34 As methylmercury is the primary route of exposure to both humans and wildlife, it is critical to understand the  
37 relationship among its concentration of methylmercury in fish, levels of ambient mercury in the environment, and  
40 emissions from all sources. While there may be uncertainty and debate about the appropriate value of the RfD, it is  
universally accepted that fish consumption dominates the pathway for human and wildlife exposure to methylmercury.  
Thus, better understanding of this pathway and, to the extent possible, the development of quantitative relationships  
among fish intake and methylmercury burden, residuals in the environment, and emissions will reduce uncertainty in  
risk assessment and risk management. Information on this issue will assist the Agency in prioritizing management of  
the diverse sources of mercury in the environment from regulation of combustion sources, pollution prevention  
activities, remediation of residuals, and international activities.

#### 43 4.3.1.3 Prioritized Research Needs.

46 The key scientific question encompasses a number of subsidiary questions, including factors influencing  
49 global, regional, and local mercury cycles; factors controlling local deposition and methylation of mercury; and  
effective monitoring programs. Research needs have been identified in four categories that follow the predominant  
pathways of exposure from emissions to fish uptake: (1) atmospheric fate, transport, and transformation processes;(2)  
deposition of mercury from the atmosphere to terrestrial and aquatic environments; (3) fate, transport and  
transformation processes in aquatic and terrestrial environments; and (4) monitoring of spatial and temporal patterns



1 of mercury and methylmercury in fish and sensitive environments. Because of the general lack of scientific  
understanding, it is felt that research related to fate, transport, and transformation processes in all environments is of  
highest priority. Research related to monitoring is very important, but scientific understanding of methods and  
4 designs is better developed, so this category is deemed a medium-high priority.

7 EPA must also begin development of a global scale model for mercury fate, transport, and transformation.  
Risk management actions to reduce global levels of background mercury are dependent on an understanding of the  
mechanisms driving mercury flux, which aids in identification of effective mediation. Unless we understand mercury  
flux from existing mercury pools in the oceans, wetlands, aquatic sediments, Arctic tundra and ice sheets, and  
10 elsewhere it is sequestered, the context for estimating the current or near-term mercury emissions from  
anthropogenic sources will be ill-defined. There is a need to establish time lines for natural emission processes. An  
additional concern is the effect of global warming in the Arctic, and potentially enhanced release and methylation  
13 rates for mercury over the next 20-100 years because of warming trends. There is a need to understand the relative  
importance of aquatic transport of mercury across international boundaries. Tracers can be used to identify current  
and historic mercury emitter source types. Significant quantities of mercury may be transported in dissolved or  
16 particulate form within aquatic systems to food chain receptors, either from direct discharge, including erosion of soils  
or sediments within a watershed, or through air deposition to water bodies. Mercury may also cross international  
boundaries via shared waters.

19 *Atmospheric fate, transport, and transformation.* In order to provide quantitative estimates of air concentrations and  
deposition of elemental mercury, reactive gas-phase mercury, and particulate mercury in the United States, the  
22 following scientific types of information are high- priority needs:

- 25 • Information from an atmospheric modeling framework, based on ORD's new multi-pollutant air  
modeling system (Models-3), which is being developed and tested for ozone and particulate matter.  
This new system will replace the highly parameterized modeling approaches for mercury now in  
28 use. The largest process uncertainties are in cloud chemistry and dry deposition of oxidized  
mercury gas, and these issues should be the focus of a future STAR Request for Applications. As  
part of this effort, available meteorological, land use, and emissions data will be collected,  
31 formatted, and included in the modeling framework. Model runs will be performed using seasonal  
aggregation approaches to produce an annual mercury depiction that includes source attribution,  
providing better estimates of the distribution of atmospheric deposition.
- 34 • Field measurements of speciated elemental and oxidized mercury concentrations in air throughout  
a region at varying altitudes, to characterize gaseous and aqueous processes. These data will be  
used to validate models of atmospheric chemistry affecting mercury deposition and will also  
37 facilitate process understanding. South Florida is proposed because of existing interagency  
projects involving Federal, State, and local agencies that are collecting information to help define  
the atmospheric processes for the model. We need highly time-resolved air and cloud water  
40 sampling at multiple levels to define the chemical processes in action. We need long-term rainfall,  
dry deposition, and air concentration monitoring at the ground to compare to model results to  
ensure that the model is correctly simulating the atmospheric processes that lead to deposition.  
43 The study will include identification of potential mercury emission sources in the south/central  
Florida region, characterization of the vertical atmospheric profile in the region, including the  
identification of trace elements and their relative concentrations, and atmospheric modeling of the  
46 southern and central Florida atmosphere. Results will be used to determine if global, continental, or  
natural forces govern mercury deposition in the region. A protocol will be developed suitable for  
other regions of the country. This type of study has been identified as a critical need in addressing  
49 source attribution issues in South Florida, particularly in distinguishing between local and global

1 sources.

- 4 • Short-range atmospheric transport models (range of 50 - 200 kilometers) to predict air  
7 concentrations and deposition. This modeling range is needed for many analyses, such as TMDL  
10 calculations used to link specific sources on a local scale to deposition to specific watersheds and  
water bodies that may be 10 to 100 or 200 km distant. There are no existing models that are well  
adapted to this scale. Current urban-scale models generally address only 50 km, which is too  
small, while national/regional-scale models (covering nearly half the United States) do not have  
sufficiently fine resolution. ORD will examine adding this scale to its current models.

13 In order to provide quantitative estimates of air concentrations and deposition of elemental mercury, reactive  
gas-phase mercury, and particulate mercury in the United States that are associated with sources outside the United  
States, the following scientific information is needed:

- 16 • Information on the atmospheric fate of mercury species in various scenarios. In particular, little is  
19 understood about the atmospheric chemistry and fate of mercury in the Arctic, and especially of a  
recently observed mercury depletion event occurring during the Arctic sunrise, when photolytic  
22 reactions significantly affect the behavior of mercury deposited during the Spring months. The  
Agency needs to understand the mechanism for mercury depletion, and whether or not it is the  
same as for ozone. Answering these questions is critical because partitioning to particulate- and  
gas-phase would enhance the deposition of mercury to the Arctic, and increase the possibility for  
bio-uptake through the food chain, since this event occurs when Arctic ecosystems are most active.
- 25 • Information on transport mechanisms affecting cross-boundary pollution. For example, recent  
28 scientific evidence points to a rapid (3-5 day) trans-Pacific transport mechanism tied to  
meteorological conditions that could bring PBT contaminants, including mercury, to the west coast  
of North America, Alaska, and the Arctic. The data show higher levels being transported in late  
31 Winter-Spring, concurrent with the timing for Arctic sunrise. The probabilistic nature of the jet  
stream controlling trans-Pacific toxic compound (mercury) transport needs to be understood if the  
Arctic spring event is to be fully appreciated.
- 34 • Field-test results of a mercury measurement technology that has been developed to determine both  
37 urban and background concentrations of gas-phase elemental mercury and particulate mercury,  
and which can be strategically deployed throughout the world. These measurements, coupled with  
trace element and back trajectory analyses, permit the modeling of mercury transport to the United  
40 States from sources abroad. Through international cooperation, similar methods can be used  
abroad to enhance the U.S. emissions mass-balance analysis. These instruments would be used to  
43 evaluate the effectiveness over time of U.S. and international mercury emission controls. Early  
international harmonization of instrumentation and mercury sampling protocols is also needed to  
compare data and identify which data are most appropriate for use in trends assessment and  
modeling.

46 Improvements in atmospheric models will be important in the next few years, and obtaining information on  
the chemical species and physical form of mercury in emissions, in the atmosphere, and in deposition is vital to  
accurate modeling of the transport and fate of mercury. There is a clear need for atmospheric models (range of 50 to  
49 200 kilometers) to be used in the development of emissions limits to protect water quality and public and ecological  
health.

1 *Aquatic and terrestrial fate, transport, and transformation.* Initial exposure research efforts will identify aquatic  
systems that have characteristics for significant methylmercury production. Initial efforts will focus on lotic systems,  
4 but models are also needed for lentic systems. Models of key parameters that promote methylmercury production  
(i.e., bacteria activity, sulfur, organic carbon, and bioavailability of Hg) will focus the risk characterization on systems  
7 and receptors that have a high likelihood for exposure. Research will evaluate the variability in methylmercury  
production among aquatic systems in the same region to characterize key parameters. There is a critical need to  
develop a better understanding of the processes (especially microbial and plant-mediated processes) that mediate  
10 ecological exposures to methylmercury. A key need is to understand the environmental cycling of mercury, especially  
the characteristics that induce methylation of mercury in ecosystems, and the pathways of mercury and  
methylmercury exposures to fish and marine mammals. ORD has prepared a STAR RFA for advertisement in FY99  
13 in this area. Results of the RFA, along with continuing internal research, will be used to improve fate, transport, and  
transformation models for aquatic and terrestrial systems to examine benefits of mercury deposition reductions and  
develop a protocol for TMDLs for mercury.

16 Terrestrial and aquatic models incorporating current process understanding at different scales should be  
developed and validated. These models must be fully consistent and integrated with the atmospheric models  
discussed above. In cooperation with other Federal, State, and local agencies, ORD will also complete field and  
19 model studies in South Florida, and then test and apply the techniques developed to the Northeast and Midwest along  
the Canadian border, to western mining issues, and to coastal and high-elevation ecosystems. This project will  
develop a spatially structured model for describing and predicting the processes controlling mercury and  
22 methylmercury exposures for fish and wildlife under current and restoration conditions. The objective of the project is  
the construction of biogeochemical and community bioaccumulation models that interface with the hydrology and  
water quality models that are the basis for evaluating restoration goals. Such a linked, spatially distributed model will  
25 be critical for assessing multiple interactive stressors, for analyzing the spatial component of mercury and  
methylmercury exposures (e.g., methylmercury concentrations in local fish populations vs. nesting/foraging areas for  
wading birds), and for evaluating the effectiveness of criterion-based restoration goals. Work in South Florida  
28 presents a unique opportunity to leverage ongoing studies with other Federal agencies (e.g., Fish and Wildlife  
Service, National Park Service, EPA Region IV), the Florida Department of Environmental Protection, the Florida  
Game and Fish Commission, and the South Florida Water Management District.

31 Because of bioaccumulation of mercury as methylmercury within the aquatic food web, piscivorous wildlife  
and humans who consume fish may experience substantial exposures to methylmercury. Ecologically important for  
34 the biological food chain is the fact that transboundary transport of mercury can occur via key piscivorous, migratory  
species which share residence time in other countries where exposure and uptake of mercury in biota may be  
enhanced. Mercury may be transported to the United States by a biological vector mechanism. It is known that  
37 migratory fish species such as salmon, marine mammals, and migratory birds share aerial ranges and residence time  
in waters or lands within other countries where mercury exposure and uptake may be higher than in the United  
States. These animals, along with bird eggs, are major dietary components in some indigenous Alaskan villages.  
40 Critical questions for wildlife exposure and biological transport to man include: (1) to what extent does transboundary  
transport of mercury occur via migratory species when boundaries are shared between the United State and other  
countries (including shared water bodies), (2) and how significant is this fish and wildlife migration for vulnerable  
43 wildlife and human populations in the united states due to uptake through the food chain? EPA knows that older fish  
of some species have elevated levels of mercury, and that same is true of beluga wales and see otters. Like wis,  
there are concerns for mercury levels in birds such as eider (an endangered species) and loons. Information about  
46 migratory patterns and behavior of migratory fish, marine mammals, migratory birds and other species of importance  
in the food chan is needed.

49 *Monitoring of atmospheric deposition.* ORD will begin development of a coordinated mercury monitoring program, in

1 cooperation with the USGS and other Federal and State agencies, through installation of comprehensive deposition  
monitoring stations in a highly impacted, highly sensitive geographic regions such as South Florida, the Northeast, the  
4 upper Midwest, and the Arctic. Of particular importance is obtaining data on the spatial and temporal distribution of  
mercury deposition to determine source-receptor relationships and to measure patterns of long-range deposition.  
7 The objective is to quantify the contributions of mercury to terrestrial and aquatic systems from local, regional, and  
global sources. To address this question, ORD proposes the development of specialized platforms for atmospheric  
10 mercury deposition monitoring and source attribution. The platforms will be capable of comprehensive speciated  
measurements of mercury and related species and will provide deposition data to compare with source-signature  
13 information. We anticipate that the platforms can also provide valuable information on mercury deposition resulting  
from international sources, and will contribute to agreements such as the US-Canada Binational Agreement and the  
North American Regional Action Plan for Mercury developed by the North American Commission on Environmental  
Cooperation. The platforms will have the capability to report on hourly-to-daily, dry and wet deposition of speciated  
mercury needed for transport and fate models, source identification, controls planning and, ultimately, direct  
measurement of mercury control benefits.

16 *Monitoring of methylmercury in fish.* The Clean Water Action Plan calls for a survey of a wide range of pollutants in  
fish tissue (including mercury). There are two basic goals: (1) to provide a statistically representative distribution of  
19 those chemicals known to accumulate in fish flesh and (2) to determine whether there are other chemicals of concern.  
This survey must be statistically based so that it is repeatable and able to detect trends in mercury to measure  
22 progress toward attaining GPRA goals. There is a critical short-term need for ORD's EMAP program to assist in  
developing the survey design for the Office of Water. This technique has proven effective in a survey of  
25 Northeastern lakes (Yeardley et al., 1998). To complement the national survey, there is a need to develop a longer-  
term monitoring program to link existing and planned deposition monitoring sites with sentinel environments where  
mercury methylation is most likely (e.g., wetlands). These sites would include atmospheric, water, soil/sediment, and  
28 tissue monitoring, including additional parameters such as C, N, P, and S that interact with mercury. A weighted  
sampling design would be developed for long-term mercury monitoring within each EPA Region, to include fish  
31 monitoring on a broad scale with more intense monitoring at a reduced subset of sentinel wetland sites to include key  
interacting variables. The design should be stratified through time with a power analysis to develop long-term data  
sets. If the design was stratified so that fish and sentinel-environment monitoring occurred in alternate years, the cost  
might be held relatively constant and the long-term need built in.

#### 4.3.2 Measures of Success

34 Researchers hope to obtain the following:

- 37 • Measurable improvement in the scientific understanding of the linkage between fish methylmercury,  
ambient mercury in the environment, and emissions.
- 40 • Completion of a national sampling plan for methylmercury and other persistent chemicals in fish  
tissue.
- 43 • Successful demonstration of a monitoring platform capable of measuring the spatial and temporal  
distribution of mercury deposition to determine source-receptor relationships and to measure  
patterns of long-range deposition.
- 46 • Completion of a multimedia integrated modeling system capable of quantifying regional exposure to  
mercury.

#### 4.4 HUMAN EXPOSURE

1 **4.4.1 Key Scientific Question #4:** *How much methylmercury are humans exposed to, particularly what are the*  
4 *exposures of women of child-bearing age and children among highly-exposed*  
*population groups; what is the magnitude of uncertainty and variability of mercury*  
*and methylmercury toxicokinetics in children?*

7 **4.4.1.1 Background.**

10 Consumption of fish and of marine birds and mammals represents more than 95 % of the human intake of  
13 methylmercury. Within the United States, individual consumption of fish/seafood is highly variable. Approximately 1%  
16 to 2% of the U.S. population report eating fish daily, whereas about 10% rarely consume fish. The *Mercury Study*  
19 *Report to Congress* (EPA, 1997a) conducted extensive analyses of fish consuming habits/patterns among the  
22 general U.S. population and high-risk sub-populations. To improve the human-exposure estimate on the basis of  
25 surveys of fish consumption, more study is needed within both the general population and potentially high-end fish  
consumers. This work would examine specific biomarkers of mercury and methylmercury exposures (e.g., blood-  
mercury concentrations and hair-mercury concentrations). This strategy assumes that the need for monitoring  
biomarkers in the general human population will be met by an add-on to NHANES-IV, funded by EPA and other  
Federal agencies, that focuses on highly exposed groups and other research needs. This survey will be large  
enough to produce reliable estimates of the 95th and 99th percentiles of mercury tissue levels in the general  
populations of women of child-bearing age and children. The survey will include dietary questions; however, it will not  
be able to estimate the distribution of levels in such particularly highly exposed sub-populations as Alaskan Natives,  
some Indian tribes, and people of Asian descent. Research is needed to fill this data gap. Toxicokinetic models for  
methylmercury are available for adults. The *Mercury Study Report to Congress* indicated that research was needed  
to understand mercury and methylmercury partitioning in children from a toxicokinetic basis. Further studies of fish  
intake and methylmercury exposure among children were also cited as a research need.

28 **4.4.1.2 Program Relevance.**

31 Estimating the size of the “at risk” human population for methylmercury exposure requires data on how much  
34 methylmercury people consume from fish/seafood. Data on geographically determined variability in the  
37 concentrations of methylmercury in fish/seafood are critical to estimating local impacts of control technologies and  
40 pollution prevention efforts. This information also provides a baseline against which the impact of future  
environmental interventions can be assessed. In particular, there is controversy concerning the size of the U.S.  
population exposed at levels comparable to those in ongoing studies of fish-eating and wildlife-eating sub-  
populations. The Children’s Health Executive Order requires consideration of children as an “at risk” population. It is  
known that children experience one-to-two times higher exposures (on a body-weight basis) to methylmercury at  
comparable concentrations of methylmercury in fish.. Because the nervous system continues to develop during the  
first six years of life, post-natal exposures to methylmercury may damage the nervous system after birth. It is not  
known whether young children are more like fetuses or adults with respect to CNS-based methylmercury toxicity.  
This combination of higher exposures and uncertainty with respect to vulnerability makes research on exposures,  
toxicokinetics, and effects of methylmercury on children a high priority.

43 **4.4.1.3 Prioritized Research Needs.**

46 *Monitoring of highly exposed human sub-populations.* There is a need to conduct biological monitoring of sub-  
49 populations who consume large amounts of fish and seafood in order to determine methylmercury intakes from diet  
and monitor blood- and hair-mercury concentrations. These sub-populations should include young children as well  
as adults and ethnically diverse groups. The sub-populations should include groups who ingest fish and marine  
mammals that are highly contaminated with methylmercury (e.g., people consuming fish from contaminated  
freshwater lakes) and those who consume high levels of fish and marine mammals with typical (e.g., 0.05 - 0.2 ppm)

1 mercury concentrations. The biomonitoring data will be collected in a way that permits development of toxicokinetic  
models that describe the tissue distributions of the comparable doses of mercury and methylmercury that are  
4 ingested in diverse temporal patterns.

7 *Development of toxicokinetic data for tissue distribution of methylmercury in young children.* Research is needed to  
establish the kinetic patterns (e.g., tissue distribution, ratios of hair mercury to blood mercury to dietary intakes) of  
mercury distribution following ingestion by children of methylmercury from dietary sources. Such data would form the  
basis of a toxicokinetic model for predicting changes in risk from changes in the amount of exposures to mercury and  
methylmercury.

#### 10 4.4.2 Measures of Success

13 Researchers hope to obtain the following:

- 16 • Measurable improvement in the scientific understanding of the variability in fish/methylmercury  
consumption among the most highly exposed sub-populations in the United States.
- 19 • Measurable improvement in the scientific understanding of the relationship between risk from fish  
and marine mammal consumption during childhood and risk from fish and marine mammal  
consumption during fetal development.

### 22 4.5 RISK MANAGEMENT FOR COMBUSTION SOURCES

25 **4.5.1 Key Scientific Question:** *How much can mercury emissions from coal-fired utility boilers and other  
combustion systems be reduced with innovative mercury control technologies;  
what is the relative performance and cost of these new approaches compared to  
28 currently available technologies?*

#### 31 4.5.1.1 Background.

34 Mercury releases from combustion systems are important because whatever is emitted is eventually  
deposited in water bodies or on land. The amount of mercury deposited in the United States that can be directly  
attributed to domestic combustion sources remains uncertain. However, a recent computer modeling study by the  
Northeast States for Coordinated Air Use Management (NESCAUM) indicates that 77% of mercury emissions  
deposited in the Northeast are from sources within the United States; and only 23 % come from the global pool  
(NESCAUM, 1998). In order to reduce the risks of mercury over time, cost-effective strategies are needed both  
domestically and internationally to minimize or eliminate the contribution from combustion facilities and other  
anthropogenic sources, including chlor-alkali plants, mercury-containing products, and waste management  
operations. Combustion facilities are particularly significant in the United States because 87% of the total point  
source mercury emissions are emitted by these sources. Coal-fired utility boilers are the largest single source (EPA,  
1997).

#### 43 4.5.1.2 Program Relevance.

46 Waste-combustion units and energy-production systems that contain mercury in feed materials are the  
major sources of mercury in the air. A substantial reduction of mercury emitted from waste combustion systems is  
expected to occur over the next several years as final emission standards promulgated by the Office of Air and  
Radiation (OAR) for municipal waste combustion systems (MWCs) and medical waste incinerators (MWIs) are  
49 implemented, and standards proposed by the Office of Solid Waste (OSW) for hazardous waste incinerators (HWIs)

1 are finalized. However, standards for electric utilities and other commercial and industrial boilers have not yet been  
2 proposed. Standards for commercial and industrial boilers are expected to be developed over the next two years;  
3 however, no decision has been made to reduce mercury emission from utility boilers because no technologies are  
4 considered commercially viable. As a result, mercury combustion control research will focus on determining the cost  
5 and effectiveness of options to reduce mercury releases from all types of coal-fired boiler configurations. OAR has  
6 identified research on emission reduction options for utility boilers as its highest priority. While the emphasis will be  
7 on coal-fired boilers, fundamental research on mercury behavior in combustion systems will be applicable to other  
8 boiler types, including those waste-burning industrial boilers and furnaces that OSW has identified as priorities for  
9 research. The results from the research also will be useful to international organizations and specific countries  
10 where combustion sources are a major emission source. ORD will work with the Office of International Activities  
11 (OIA) to develop appropriate technology transfer documents that summarize research findings and to provide  
12 technical support for any international demonstrations.

#### 13 **4.5.1.3 Prioritized Research Needs.**

16 Over the next three to five years, ORD will work cooperatively with DOE, USGS, and private sector  
17 organizations including EPRI to address the key scientific questions above. Studies will be conducted to identify,  
18 evaluate, and demonstrate innovative technological solutions that can cost-effectively reduce mercury emissions  
19 where standards have not been issued or where improved technologies would significantly reduce the costs to  
20 comply with existing regulations. The selection of mercury emission control methods is driven by both performance  
21 and cost considerations. Sorbents that have improved performance for both ionic and elemental forms of mercury  
22 need to be investigated. The relative costs of controlling only mercury and of controlling mercury in conjunction with  
23 other pollutants such as fine particulate matter (PM) and fine PM precursors (SO<sub>2</sub> and NO<sub>x</sub>) also need to be  
24 quantified.

25 This section of the plan also encompasses research to improve devices to measure mercury emissions.  
26 These devices are needed to support control options (i.e., mercury species being emitted) and to determine  
27 compliance with regulations. The four research areas identified below (listed in priority order from highest to lowest)  
28 were chosen based on priorities identified by OAR, OSW, and external stakeholders; scientific uncertainties (data  
29 gap analysis) that now impede implementation of mercury controls for specific sources; and the potential to reduce  
30 control costs.

34 *Determine the parameters that affect mercury species emitted from combustion systems and identify potential  
35 approaches to capture these species.* In combustion systems, mercury is volatilized and converted to elemental  
36 mercury (Hg<sup>0</sup>) in the high-temperature regions of furnaces. As the flue gas is cooled, mercury is oxidized to ionic  
37 forms (Hg<sup>++</sup>). The rate of oxidization is dependent on the temperature, flue gas composition, and the amount and  
38 properties of entrained particles (fly ash and sorbents). Hg<sup>0</sup> and HgCl<sub>2</sub> are in the vapor phase at flue-gas cleaning  
39 temperatures, and special methods must be used for their capture. Each of these forms of mercury can be adsorbed  
40 onto porous solids such as fly ash, powdered activated carbon, and calcium-based acid-gas sorbents for subsequent  
41 collection in a PM control device. These mercury compounds can also be captured in carbon bed filters or other  
42 reactors containing appropriate sorbents. In the United States, the control of mercury in MWCs and MWIs is based  
43 on the injection of powdered activated carbon upstream of an electrostatic precipitator or fabric filter. HgCl<sub>2</sub> is water  
44 soluble and readily reacts with alkali metal oxides in an acid-base reaction; therefore conventional acid gas scrubbers  
45 used for SO<sub>2</sub> control are effective in controlling HgCl<sub>2</sub>. Hg<sup>0</sup> is insoluble in water and must be adsorbed onto a sorbent  
46 or converted to a soluble form that can be collected in a wet scrubber. Ionic mercury also has low solubility and must  
47 be controlled by methods similar to those used for Hg<sup>0</sup>.

49 In incinerators, the flue-gas concentration of chlorine, in the form of hydrogen chloride (HCl), is substantially  
50 higher than the concentration of Hg<sup>0</sup>. In these cases, Hg<sup>0</sup> is preferentially converted to mercuric chloride (HgCl<sub>2</sub>). In

1 coal-fired combustors, where the concentrations of HCl are much lower and SO<sub>2</sub> is present, Hg may remain  
predominantly in the elemental form. A fundamental understanding of the parameters that influence the mercury  
species present in a combustion system is therefore essential to determine what approaches will provide optimal  
capture. Specific activities planned are to: (1) understand the chemical and physical properties of various mercury  
species in order to quantitatively characterize the behavior of major mercury species in combustion systems; (2)  
quantify the chemical reactions or reaction mechanisms that affect mercury species in flue gases, particulate matter  
control devices, and dry and wet scrubbers; (3) determine how fuel or waste properties and combustion conditions  
(temperatures, residence times, quench rates, flue gas composition, fly ash particle properties, and sorbent  
properties) affect mercury speciation; (4) evaluate whether the species of mercury can be controlled by using  
reagents, catalysts, or adjustments to the combustion process conditions; (5) identify fly- ash and flue-gas properties  
that lead to high levels of mercury adsorption; (6) determine whether changing combustion conditions will enhance  
adsorption; (7) determine the solubility of different mercury species as a function of different operating conditions  
(temperature, dissolved combustion products, flue-gas cleaning reagents, and scrubber-reaction products); and (8)  
determine the scrubber conditions necessary to convert Hg<sup>0</sup> to the easier-to-capture HgCl<sub>2</sub>. ORD will conduct bench-  
and small pilot-scale research on mercury behavior and innovative capture methods, and the most promising  
innovations will be evaluated on larger pilot-scale facilities. This research program directly responds to research  
needs 5 and 6 identified on page 5-7 of the Executive Summary of the *Mercury Study Report to Congress* (EPA,  
1997).

19 *Develop information on performance and cost of specialized sorbents, reagents, and control equipment that can be  
used to reduce mercury emissions from utility boilers and other combustion sources.* Conventional flue gas cleaning  
technologies are not always appropriate for controlling mercury emissions, and special sorbents, reagents, or  
equipment must be used for more effective control. The performance of technologies for controlling mercury  
emissions is dependent on a number of factors that include the effectiveness of sorbents and reagents and the  
physical/chemical conditions that determine mercury capture (temperatures, resident times, flue-gas composition, fly-  
ash properties, sorbent concentrations, reagent concentrations, and the diffusion or mixing of reactants). Based on  
the mercury speciation, control mechanisms and sorbent development research, field tests will be conducted to  
evaluate the effectiveness of different equipment configurations and process conditions in controlling mercury  
emissions, including techniques to control the species of mercury and to characterize the performance of sorbents  
and reagents. In addition, engineering cost studies will be conducted to provide estimates of capital and operating  
expenses for the control technologies considered. ORD plans to conduct this research collaboratively with EPRI  
and DOE and expects that a substantial amount of the funding for any full-scale utility demonstrations will be provided  
by one or both of these research partners.

34 *Evaluate continuous emissions monitors that are sensitive enough to measure total mercury and the species of  
mercury present in emissions even at very low concentrations.* The ability to develop effective control technologies  
and determine compliance with regulations, and the need for improved information to support risk assessments  
requires more sensitive devices to measure total mercury and better information on the species of mercury emitted  
from the stack. A reference method is available to speciate different mercury species in coal-fired boiler stack gases  
(the Ontario-Hydro Method). Neither this nor any other method is capable of accurately measuring the species of  
mercury upstream of air pollution control devices. Particulate matter can cause catalytic reactions that oxidize Hg<sup>0</sup> as  
it passes through the sampling train. This increases the difficulty of determining the behavior of mercury in flue  
gases and of developing effective pollution control technologies. Several commercial continuous emission monitors  
are now used in Europe to measure total mercury in municipal waste incinerator flue gases. U.S. trials of these  
CEMs on a cement kiln and a pilot-scale coal fired combustor were not successful. In addition, several vendors are  
attempting to develop a mercury CEM that is capable of differentiating the species of mercury. It will probably be at  
least two years before these units will be ready for field validation testing. Research is needed to: (1) identify the  
appropriate methods of measuring total mercury and the mercury species (the chemical forms of Hg) in combustion  
system flue gases; (2) determine if one method will work for all combustion sources or whether different methods



1 must be used; and (3) evaluate whether continuous measurements of mercury are necessary to confirm the  
effectiveness of feed limitations and whether they will reduce costs (i.e., prove that emissions levels have been met  
4 without costly sampling of input stream). Page 5-1 of the Executive Summary of the *Mercury Study Report to  
Congress* (EPA, 1997a) identified "Development and validation of a stack test protocol for speciated mercury  
emissions" as a research need.

7 *Characterize mercury-contaminated residuals from air pollution control systems and, if needed, determine the cost  
and performance of technologies that can stabilize the residuals before they are sent for land disposal.* Flue gas  
10 cleaning technologies generate mercury-bearing residues that must be recycled or sent for land disposal. In order to  
ensure the mercury is not simply released into another medium (i.e., soil or groundwater), the combustion research  
program must include a component that will characterize the residues and determine whether anything must be done  
13 to stabilize the mercury before it is sent for land disposal. Research is needed to characterize the levels of mercury  
present in residuals after installation of innovative flue-gas-treatment technologies, and evaluate the cost and  
performance of stabilization technologies.

16 In addition to the four research areas above, other Federal agencies and the private sector need to conduct  
studies to evaluate improved techniques to clean coals prior to combustion. ORD does not plan to conduct research  
19 in this area, but will summarize the results of any research conducted when it produces an update for OAR on the  
performance and cost of emission reduction options for coal-fired utility boilers.

#### 22 4.5.2 Measures of Success

25 Researchers hope to obtain the following:

- 28 • Identification of the combustion conditions that have the most significant impact on the species of  
mercury formed in coal-fired utility boilers
- 31 • On the basis of the above information, design innovative control systems for testing at a larger  
scale.
- 34 • Identification and field evaluation of improved devices to measure both total mercury and species of  
mercury.
- 37 • Successful demonstrations, at full-scale, of innovative options (including performance and cost) to  
reduce mercury emissions from coal-fired utility boilers.
- 40 • Integrated outputs that summarize information on the relative performance and cost of reducing  
mercury emissions using pretreatment approaches, flue gas cleaning technologies, or  
combinations of both, that can be used by both internal (OAR) and external (utilities) customers to  
make decisions on how to control mercury emissions from combustion systems.

#### 43 4.6 RISK MANAGEMENT FOR NON-COMBUSTION SOURCES

46 4.6.1 Key Scientific Question #6: *What is the magnitude of contributions of mercury releases from non-combustion  
sources; how can the most significant releases be minimized?*

##### 49 4.6.1.1 Background.

This section describes proposed research activities to manage mercury releases from non-combustion

1 sources, encompassing all non-combustion activities over the anthropogenic life cycle of mercury from extraction and  
refining through use to disposal. Releases of mercury to any environmental medium (air, ground or surface waters,  
or soil) are included. While available data on the use and release of mercury in this category are limited, some  
4 available data indicate the total disposition of mercury by various segments of this category in the U.S. In 1995 this  
category consumed 436 tons of mercury and contributed about 13 % (20 tons) of U.S. mercury emissions. In that  
year over 12.2 million metric tons of mercury-bearing hazardous wastes were generated (OSW -- EPA, 1998), and an  
7 estimated 227 tons of mercury were disposed of in municipal landfills as part of mercury-bearing solid wastes. EPA  
(1997a). International data on mercury use and releases are difficult to obtain. For non-combustion sources, a few  
countries (e.g., Sweden) appear to be more advanced in reducing mercury use. However, many other countries,  
10 especially developing nations, use much more mercury than the United States and have fewer controls. (Unless  
otherwise stated, all discussions in this section deal with use and release of mercury in the United States.)

13 Because of the wide variety of sources and difficulties in measuring mercury emissions, estimates for some  
U.S. sources are believed to be low. Additionally, these sources generally have low stacks or vents (and in some  
cases release soluble mercury compounds, such as  $HgCl_2$ ) that result in higher rates of local impacts per unit  
16 emissions compared to combustion sources. The numerous activities that use mercury produce mercury-bearing  
wastes and consumer products (including bulk elemental mercury) that will pose a long-term threat to the  
environment if not disposed of properly. EPA Program Offices believe that the magnitude of releases of mercury to  
19 soils and water by non-combustion sources is relatively small. But these releases are the source for local hot spots of  
mercury, and those that are significant need to be minimized.

#### 22 4.6.1.2 Program Relevance.

25 As reflected in the *EPA Action Plan for Mercury*, the Agency proposes to reduce mercury releases from  
these sources through a number of tactics, including regulations (e.g., MACT for chlor-alkali plant emissions) and  
promotion of voluntary activities by industry (e.g., hospitals, chlor-alkali plants). Site- and facility-specific problems  
are being addressed by Regional Offices. The results of improved approaches to reducing releases in the U.S. will  
28 carry over to the rest of the world, as evidenced by a number of EPA activities undertaken with other countries to  
enhance emissions reductions. Research described in this section supports a number of these Agency activities.

#### 31 4.6.1.3 Prioritized Research Needs.

34 Based on the focus of Agency mercury-reduction activities and on a preliminary evaluation of the  
significance of mercury releases, five areas of research were identified: (1) chlor-alkali facilities, (2) waste disposal  
and recycling, (3) other sectors of the economy utilizing mercury, (4) contaminated soils and sediments, and (5)  
mining. The first three were ranked as high- priority areas. Research on contaminated sediments and mining was  
37 ranked as medium priority, while research on contaminated soils was ranked as relatively low priority. Risk  
management research that could be done in any of these areas included improved characterization of releases,  
source reduction, release control and, in the case of contaminated sites, site remediation. In addition, the need for  
40 "risk management assessments" was considered; these would be screening-level evaluations of selected types of  
sources to focus risk management research and evaluate the environmental and economic costs and benefits of  
various management options. Four overarching research and technology transfer needs emerged for risk  
43 management of non-combustion sources: (1) improved characterization of mercury releases, particularly emissions,  
for selected sources; (2) application of source reduction options wherever possible to minimize future utilization of  
mercury; (3) application of risk management assessments in both the combustion and non-combustion source  
46 categories; and (4) international transfer of technologies for reducing the use and release of mercury.

49 *Chlor-alkali Industry:* The chlor-alkali industry, which uses a mercury cell process in 14 U.S. facilities to produce  
chlorine and caustic (NaOH and potash), is the largest non-combustion emitter of mercury (7.1 tons/yr, or 35 % of all

1 non-combustion sources). The U.S. chlor-alkali industry's average annual mercury usage for the period 1990 to 1995  
was 160 tons (about equal to the total U.S. mercury emissions in 1995). Only 32 tons of this use is accounted for by  
Toxic Releases Inventory (TRI) data. Facilities can house from 100 to 500 tons of mercury, which during the  
4 production process is heated to about 200 degrees F. Cell rooms are designed to maximize ventilation in order to  
protect workers, thereby increasing emissions to the atmosphere. Emissions are not easy to measure (see below),  
and they likely vary with operating conditions and ambient temperatures. For these reasons, EPA estimates of  
7 emissions are probably low. OAQPS is developing Maximum Achievable Control Technology (MACT) regulations for  
these facilities under CAA Section 112(c)(6). These are scheduled to be proposed in 1999 and promulgated in 2000.  
Emissions characterization and control for cell rooms are particularly difficult because of their design and the episodic  
10 nature of releases (e.g., during cell opening for cleaning), and because many of the releases are fugitive. OAQPS is  
also analyzing the MACT residual risk, but this may be difficult because of poor emissions factors.

13 Region V has the Agency lead for coordinating with the Chlorine Institute and its member firms to support  
their voluntary program, announced in 1996, to reduce mercury use and release in response to the Binational Toxics  
Strategy with Canada. The firms have agreed to reduce mercury use and release by 50 % (from 160 tons/yr to 80  
16 tons/yr) by 2006 and have several task forces on factory mercury mass balance, release reduction, and related  
topics. The industry expects to achieve its emissions reductions goals. There are large uncertainties about the fate of  
mercury used in chlor-alkali plants (CAPs) and difficulties in characterizing and controlling mercury release to the  
19 environment from some facility processes. Improved approaches are particularly needed to characterize mercury  
releases from cell rooms.

22 Research would involve determining more accurate means to measure cell room emissions and determining  
appropriate emission factors. Because of the potential significance of these emissions, ORD research needs to start  
in 2000. If improved emissions factors confirm mercury emissions to be significant, studies also need to be  
25 conducted to determine means to reduce mercury emissions through control and/or source reduction, and estimate  
the relative costs and impacts of appropriate techniques. Studies to identify all fate pathways for mercury may also be  
needed. The Chlorine Institute is studying all these topics to varying degrees. ORD will conduct a preliminary  
28 assessment that addresses these issues. The results of this study will be used to help guide Agency policy decisions  
and to support ORD in providing technical input to the Chlorine Institute in cooperation with Region 5 and EPA  
Program Offices. Such an assessment needs to be started in 2000 for ORD to be able to affect the Chlorine Institute's  
31 work. Given the potentially large emissions of mercury from CAPs and their preferred use in developing countries  
(due to their relatively low cost), CAPs need to be included in the inventory of international emissions sources. In  
addition, ORD should support reducing these emissions by producing technology transfer documents that describe  
34 effective techniques for characterizing and reducing those emissions.

37 *Waste Disposal and Recycling.* Proper disposal of mercury is a priority issue. As mercury is an element, it must be  
permanently immobilized or confined to ensure that it does not volatilize or leach to surface or ground waters. OSW  
is revising the Land Disposal Restriction (LDR) for mercury-bearing hazardous wastes because of concern about  
several issues, including air emissions from the current LDR treatment technologies (incineration and retorting),  
40 alternatives to thermal processes, and long-term effectiveness of solidification. OSW's current schedule is to produce  
a proposed rule in mid-2000 and a final rule in mid-2001. As noted, OSW wants to compare the effectiveness of  
alternatives to thermal treatment, particularly solidification/stabilization and non-thermal recycling alternatives, to meet  
43 RCRA standards while minimizing air emissions. OSW is also reevaluating the use of the TCLP for various disposal  
scenarios, including solidification/stabilization, monofilling, and delisting, as well as management of mineral  
processing wastes. OSW is also considering regulatory incentives that would encourage companies to invest in  
46 manufacturing process redesign, raw materials substitution, or other technologies that would reduce the amount of  
mercury found in hazardous waste.

49 Research is needed to clarify the effectiveness of various solidification/stabilization processes so that they

1 can be compared with other alternatives to the incineration and retorting of mercury-bearing wastes. DOE is  
conducting research on alternative treatment techniques for mixed wastes, including solidification/stabilization. ORD  
will address other waste matrices covered by RCRA, investigating the factors that determine the effectiveness of  
4 solidification/stabilization processes. Rutgers University will be doing work for OSW to evaluate alternatives to the  
TCLP. ORD will participate in a technical advisory capacity. This research has been initiated and needs to be  
continued through about 2002 to support OSW regulation development and any following implementation issues.  
7 Although of lower priority, research is also needed on the extent to which mercury is released from municipal landfills  
through volatilization or leaching, and on how these releases can be reduced. Existing, but limited, data suggest that  
these processes are not significant. ORD will conduct a preliminary assessment of landfill mercury releases to  
10 determine whether there is a need to pursue improved controls (including pretreatment) further. The assessment  
needs to be conducted as soon as possible so that improved landfill controls can be addressed if results indicate the  
need.

13 *Other Sectors.* Although the overall domestic demand for mercury in the United States has declined in recent years,  
its consumption is still growing or declining only slightly in a number of industrial sectors. These include electric  
16 lighting, electronic equipment, wiring devices and switches, measurement and control instruments, dental equipment  
and supplies, laboratory uses, and medical uses. About 190 tons of mercury were used by these sectors in 1997.  
EPA (OPPT and Region V) is pursuing a number of voluntary initiatives to reduce mercury use and releases.  
19 Ongoing and planned mercury reduction actions include outreach to hospitals, outreach to manufacturers and users  
of mercury switches and relays, and collaboration with laboratory facilities. As part of its focus on PBTs, OSW is  
evaluating ways to reduce the generation of mercury-bearing hazardous wastes, particularly those being combusted.  
22 In addition, EPA (OIA, OPPT, Regions V and X) is participating in international activities to encourage reductions in  
mercury use and releases. These include the Great Lakes Binational Toxics Strategy, a North American Regional  
Action Plan, and the U.N. Long-Range Transboundary Air Pollution (LRTAP) protocol on mercury and other heavy  
25 metals. Source reduction is a principal component of all these activities.

28 Mercury consumption in some of these sectors may not be well established; such information is needed to  
set targets for mercury-use reductions and to monitor reductions. The amount of releases from individual sectors is  
uncertain, with the result that the environmental impacts of continued use are not always well known. Identifying  
31 sectors where source reduction has the greatest potential and conducting that work is of highest priority. Developing  
improved emissions characterization will be necessary if preliminary assessments indicate that emissions may be  
large and difficult to measure (i.e., similar to CAPs). For ORD to have an impact by 2005, an initial assessment is  
needed in the near term to determine where additional collaborative activities with industry might be most beneficial.  
34 Such collaboration would include providing systems analysis tools such as Life Cycle Analysis (LCA) to help industry  
determine the economic, energy, and environmental costs and benefits of management options. Technology transfer  
mechanisms (e.g., workshops, electronically available documents) would be developed to support industry's efforts.  
37 This work with selected sectors would proceed from approximately 2001 to 2005. Longer term, release control  
research may be needed if releases are significant and source reduction will not be effective. Documents to support  
international technology transfer of source reduction and control techniques need to be among the products from  
40 research in this area.

43 *Contaminated Sediments and Soils.* Sediments are a significant sink for air- and water-borne mercury emissions  
from combustion and non-combustion sources. Sediments are also host to the base of the food web that extends  
through aquatic organisms to land-based animals and humans. Mercury was a risk driver at 29 % of the stations  
46 sampled in the recent national sediment survey; it is also the contaminant responsible for many of the fish  
consumption advisories throughout the country. There are also a number of sites with significant contaminated  
mercury in soil, and while elemental mercury in soil is not highly mobile, it may be methylated and enter the terrestrial  
49 food chain. Sediments and soil hot spots appear to be the only places in the environment where mercury can be  
cost-effectively removed from the global pool.

1 Several offices in EPA have an interest in mercury-contaminated sediments. The Office of Water has a  
broad responsibility that includes past and current practices that contribute to diffuse, low-level mercury  
contamination with impacts on surface water quality, aquatic life, and terrestrial organisms. OSWER, under the  
4 Superfund program, evaluates locations with contaminated sediment to determine if they should be placed on the  
NPL and subsequently cleaned up. If contaminated sediments present an immediate threat to human health or the  
environment, the Superfund program can also take a removal action without going through the NPL listing process.  
7 Regions with sediment Superfund sites or major sources of mercury contamination (e.g., CAPs) have site-specific  
concerns about mercury-contaminated sediments. Contaminated sediments are a component of the Great Lakes  
Binational Toxics Strategy, for which Region 5 has the lead. Contaminated soils are addressed by EPA Superfund  
10 and RCRA Corrective Action programs; ORD is not aware of any special efforts in EPA to address the remediation of  
mercury-contaminated soils.

13 Two avenues are available for management of mercury in sediments: in-place methods and dredging  
followed by confinement or treatment. Research is needed on in-place management of mercury-contaminated  
sediments that focuses on natural processes that sequester mercury from the food web. These processes include  
16 physical disruption of the exposure path (e.g., clean sediment deposition), chemical alteration of the mercury to less  
bioavailable or biotoxic forms, and biological transformation or sequestration. Once the mechanisms are understood,  
in situ methods to enhance the natural control activity can be investigated. Because the weight of evidence suggests  
19 that methylmercury from contaminated sediments contributes significantly to concentrations in fish, bench research  
on processes to disrupt methylmercury production needs to be initiated in the near term, followed by field testing that  
will take 4 to 6 years to complete.

22 Research on remediation options for soils contaminated with mercury is a lower relative priority in the non-  
combustion source category, although remediation of these sources must ultimately be addressed. Contaminated site  
25 remediation may be of high priority on a site-specific basis, such as at DOE sites. Remediation options for such sites  
are under development by DOE and should continue. Whenever possible, information on remediation options for soils  
should be collected during mercury remediation/treatment research on waste streams, mining, and contaminated  
28 sediment, and during more broadly-scoped remediation research for metals in soils.

*Mining.* Mining and mineral-processing wastes can be significant sources of local mercury contamination, and  
31 potentially affect air and water resources, thus posing threats via deposition in sediments followed by magnification  
through the food web. Most mercury releases from operating U.S. mines are well controlled, but this is not true  
internationally (e.g., in Mexico). The large volume of abandoned mining wastes remains uncontrolled and is not  
34 amenable to conventional management strategies. Region IX has particular interest in research on mercury from  
mining sources. EPA Region IX is currently involved with the Sulphur Bank Mercury Mine Superfund Site and its  
impacts on Clear Lake. The San Francisco Regional Water Quality Control Board is closely monitoring the discharge  
37 of mercury and sediment from an abandoned mercury mine in a watershed that drains into Tomales Bay, one of  
California's most pristine estuaries. The site currently has Superfund and TMDL work scheduled. Region IX is also  
developing mercury TMDLs for two lakes in southern Arizona. These lakes are very close to each other and have  
40 fish populations with mercury above 1 mg/kg. One lake has a known mercury source, an abandoned mine, in its  
watershed, while the other lake does not have any known mercury source. Other EPA Regions with a significant  
history of base- and precious-metal mining are likely to be facing similar questions.

43 ORD does not have adequate data to assess the relative impact of these mining sites compared to other  
non-combustion sectors or other metals from mining. A limited assessment is needed to determine the priority of  
46 control research relative to research on other metals. Because of the priority of metals contamination in Region IX  
and elsewhere in the West, the assessment needs to be done in the near term. If this assessment confirms the  
priority of mercury mining research, studies of treatment options for solids and runoff should be conducted starting in  
49 about 2001. Such research would investigate new, low-cost management methods needed to control mercury

1 releases. Research needs to be conducted to interrupt the important transport pathways of mercury, focusing on  
wastes known to be degrading watersheds. This work would be performed in partnership with Region IX and with  
4 ORD's Congressionally-mandated Mine Waste Technology Program; cost-sharing with the latter will provide sufficient  
funds to conduct the field studies needed to investigate remediation methods.

#### 7 **4.6.2 Measures of Success**

##### *Chlor Alkali Industry Releases*

10 Researchers hope to obtain the following:

- 13 • Identification and/or evaluation of technologies and techniques that provide improved facility emissions measurements.
- Improved characterization of facility mercury mass balance.
- 16 • Improved understanding of the effectiveness and cost of vendors' innovative technologies for characterization or control of mercury emissions.

##### *Waste Disposal*

- 19 • Assessment of the effectiveness, cost, and environmental impacts of solidification/stabilization processes as applied to mercury-bearing hazardous wastes.
- 22 • Recommendations for improved techniques for determining the mobility of mercury in various treatment residuals.
- 25 • Improved understanding of the extent to which mercury is released from municipal landfills, and of ways to minimize those releases.

##### *Other Sectors*

- 28 • Assessment of mercury use in the consumer sector to identify major needs and opportunities for reduced use and/or releases.
- 31 • Evaluation of one or two pollution prevention approaches for mercury using life cycle analysis, and determine of the reduction in adverse environmental impacts.

##### *Contaminated Sediments*

- 37 • Evaluation of the effectiveness of natural attenuation at two field sites.
- Improved the understanding of the processes that control mercury transport and re-speciation in the saturated sediments.
- 40 • Evaluation of the bench-scale approaches to sequestration or separation of mercury from contaminated sediments.

##### *Mining*

- 43 • Identification of waste types that contribute most to mobile mercury.
- 46 • Development and/or evaluation of three technologies to control mercury transport or bioavailability.

#### **4.7 RISK COMMUNICATION**

##### **4.7.1 Key Scientific Question #7:** *How does EPA effectively inform members of susceptible sub-populations of the*

1 *health risks posed by mercury and methylmercury contamination of fish and*  
2 *seafood?*

4 **4.7.1.1 Background.**

7 Even if current anthropogenic emissions of mercury were to cease immediately, elevated mercury and  
8 methylmercury exposures would occur for a number of years. This lag results from global recycling of mercury from  
9 natural sources and from previously-emitted anthropogenic mercury emissions. Various predictions exist regarding  
10 how long this phase would be. During the intervening years EPA needs to effectively communicate to members of  
11 susceptible sub-populations the nature and extent of risks to human health posed by methylmercury contamination of  
12 fish and seafood (e.g., marine mammals).

13 Susceptible populations include people consuming above-average amounts of fish (e.g., more than 10  
14 grams per day) on a regular basis. Higher than average consumption of fish and other seafood is found among  
15 people of Asian and Native American ethnicity, as well as among recreational anglers and their families. The extent  
16 of exposure depends on the amount of fish consumed and on the methylmercury concentrations in the fish.  
17 Methylmercury adversely affects the developing nervous system at lower exposure than it affects adults' neurological  
18 functioning. Consequently, women of childbearing age, maternal/fetal pairs, nursing mother/infant pairs, and young  
19 children are all included as susceptible sub-populations. Because brain development continues during early  
20 childhood, young children along with pregnant/nursing mothers and their infants need to be aware of the health  
21 hazards posed by ingestion of an excessive amount of methylmercury from fish/seafood. Initial efforts in research on  
22 risk communication strategies to inform these populations.

25 **4.7.1.2 Program Relevance.**

26 EPA anticipates a long lag time in controlling environmental levels of methylmercury, a known neurotoxin. It  
27 is the policy of the organization that the community must have the right to know the dangers faced and make an  
28 informed decision regarding exposure to these chemicals. This premise has formed the basis of the fish advisory  
29 programs supported by EPA and run by State and local organizations/government. An adequate research base is  
30 needed to effectively inform all risk groups of the extent of their potential exposures and provide adequate dose-  
31 response information to make an informed choice on the magnitude of methylmercury exposures produced by  
32 particular patterns of fish consumption.

34 **4.7.1.3 Prioritized Research Needs.**

35 Two major areas of research/monitoring are needed. The amount of mercury and methylmercury in fish  
36 varies markedly with geographic location, which reflects the impact of local factors. For example, similar lakes within  
37 a few miles of each other may have decidedly different bioaccumulation of methylmercury in fish. Consequently there  
38 is a need for monitoring data on mercury and methylmercury levels in water bodies and in fish. These data would  
39 provide specific information to the population consuming fish from these water bodies.

40 The second major need is to have an adequate understanding of how people utilize risk information to make  
41 informed choices regarding their mercury and methylmercury exposures. This is particularly complex because the  
42 groups at greatest risk (e.g., infants, young children) have not reached a level of cognitive development to permit  
43 such choices. Consequently the groups to reach are parents or other individuals responsible. This area of risk  
44 communication is comparatively little explored and represents a major opportunity for EPA to have an effective role in  
45 its development.

49 **4.7.2 Measures of Success**

1 Researchers hope to obtain the following:

- 4 • Mapped distribution of mercury levels in fish found in all waterways in the United States.
- 7 • Identification of the risk communication styles utilized by women of childbearing age from ethnically diverse populations.
- 10 • Identification of the sub-populations (based on ethnic, racial, economic, tribal groups) of greatest concern with regard to ingestion of mercury and methylmercury from fish/seafood.
- 13 • Development of fish advisories of proven effectiveness that reach 90% of the at-risk population.
- 16 • Development, with appropriate professional groups (e.g., obstetricians, State medical officers, State fishery experts), of risk messages aimed at informing particular sub-population.



## 5. MERCURY RESEARCH STRATEGY IMPLEMENTATION

This *Mercury Research Strategy* provides guidance and direction for ORD's mercury research program over the next five years. It is designed to identify needed research on assessing and managing risks from mercury and methylmercury. The research strategy supports EPA's Program Offices and Regions by addressing seven questions that will provide the scientific information and technical data to reduce uncertainties currently limiting the Agency's ability to address mercury. This research strategy is distinct from a mercury implementation plan, which will provide many more details (e.g., time lines, delivery dates, specific outputs) about the research proposed. ORD anticipates that the *Mercury Research Implementation Plan* will be available in FY 2000.

### 5.1 ROUTINE MONITORING AND MEASUREMENT ACTIVITIES

In the process of preparing the *Mercury Research Strategy*, two activities were identified that, while not specifically research, provide scientific data and information important to the success of the Agency's risk assessment and risk management efforts for mercury and methylmercury. Such information indicates progress in meeting Agency-wide mercury goals specified in the Mercury Action Plan and in other documents (EPA, 1998; EPA, 1999c; EPA, 1999d) where EPA has described activities or made commitments to addressing mercury. Furthermore, this scientific data and information informs the research being conducted under the strategy and allows for periodic adjustments in research strategy implementation.

#### 5.1.1 Mercury Source Emissions Information

EPA's most comprehensive emissions inventory of various U.S. anthropogenic sources, including mercury, is the National Toxics Inventory. It provides a compilation of emissions estimates for all listed hazardous air pollutants (HAPs) for point, area, and mobile sources. It incorporates information from the Toxics Release Inventory (TRI), which reflects manufacturers' submitted estimates of facility emissions to EPA; State and local inventory data; and data from other special studies. Finally, EPA is gathering mercury emission data, including speciation, for coal-fired utility plants using a Utilities Information Collection Request. With respect to information needs, EPA's current mercury emissions inventories do not include all U.S. anthropogenic sources. Also, these inventories, with the possible exception of the utilities request for information, do not contain speciated emissions values. An inventory of speciated mercury emissions nationally (and internationally) is essential in order to effectively model anthropogenic mercury releases and predict deposition and concentrations in environmental media. Finally, there is a need for trends information to demonstrate the effectiveness of various mercury reduction activities.

#### 5.1.2 Mercury Monitoring Information (of Concentrations in Various Media, e.g., Air, Water, Soils, Biota)

While no comprehensive, national monitoring network for mercury in all relevant media has been developed, there is an increasing number of monitoring activities under way. EPA and others have developed ambient air and deposition monitoring networks that address mercury (together with other pollutants) on a local or regional scale. Also, EPA has developed monitoring networks that collect information on mercury (and other pollutants) in non-air media, some of which are addressed on a national basis (EPA, 1999c; EPA, 1999d). Existing networks include:

##### Air medium

- The Integrated Atmospheric Deposition Network (IADN), a joint program with Canada, which examines deposition to the Great Lakes;

- 1 • The Chesapeake Bay Atmospheric Deposition Study (CBADS), initiated by a team of scientists from academia; and
- 4 • The National Atmospheric Deposition Program/National Trends Network, involving various Federal and State agencies, which includes a Mercury Deposition Network.

7 Non-air media

- 10 • EPA's Environmental Monitoring and Assessment Program (EMAP), which provides estimates of changes in the Nation's ecological resources on a regional basis;
- 13 • The National Sediment Inventory, which was established by EPA to provide information on sediment quality; and
- 16 • the National Contaminated Sediment Point Source and Non-Point Source Inventories, compiled by EPA.

19 Biota

- 22 • EPA is conducting a survey entitled National Survey of Chemical Residues in Fish to determine methylmercury (and other chemical) concentrations in fish.; and
- 25 • The National Center for Health Statistics administers the National Health and Nutrition Examination Survey (NHANES) which collects mercury concentrations in human hair and blood

28 Thus, while significant activities are under way, the need is increasing for development of statistically representative monitoring data in all relevant media to produce a baseline against which progress can be measured. These data must be statistically based so that surveys are repeatable and trends in mercury can be detected as part of achieving GPRA goals. In particular, data are needed in both fish tissue (the primary route of human and wildlife exposure) and in highly exposed human populations. The biomonitoring data will need to be collected in a way that permits development of biogeochemical cycling and biokinetic models that describe the tissue distributions of the comparable doses of mercury and methylmercury.

34 **5.2 ENGAGEMENT AND PARTNERSHIP**

37 While not a key scientific or technical issue, it is clear that engagement and partnering with a variety of stakeholders will enhance ORD's mercury research program. In addition to working closely with EPA's Program Offices and Regions, other organizations or groups must be engaged, including (1) the regulated community, to gain their participation and sponsorship of mutually beneficial mercury research; (2) States, communities, and tribes, to fully inform decision-makers at the community level of the research addressing mercury issues; (3) Federal organizations, to identify what research they can provide to support ORD's program; and (4) the international community, to exchange information on mercury research and development activities.

43 **5.3 RESEARCH PRODUCT DELIVERY AND UTILIZATION OF RESEARCH RESULTS**

46 The *Mercury Research Strategy* addresses the most pressing research priorities associated with mercury and methylmercury risk assessment and risk management. It flows from a number of recent reports on mercury issued by EPA, and is designed to respond to the research needs identified in those reports. When implemented, it will support the Program Offices and Regions with data and information that will assist them in making the most

1 informed regulatory and policy decisions about mercury over the next five to ten years. While ORD's internal Agency  
customers are a primary audience for these research products, the audience for the research strategy and the  
4 resulting research products goes well beyond the Agency's Program and Regional Offices. Numerous groups and  
organizations are interested by, or have a stake in, the research that will be conducted under this strategy.  
7 Examples include the U.S. Congress, regulated entities, environmental groups, community decision makers at all  
levels, and the general U.S. public. Internationally, foreign governments and multinational groups will also be  
interested.

10 It is incumbent upon ORD that the products resulting from this strategy be delivered in a form that is useful to  
all of the aforementioned stakeholders. If the products of the research are not useful, then the goal of the strategy  
and ultimately the success of making the most informed decisions with respect to mercury will not be realized. To  
13 make its products as useful as possible, ORD intends to work closely with Program and Regional Offices and other  
stakeholders to deliver its research products in a way that informs a variety of groups with varying levels of  
experience and expertise. Furthermore, these products will be delivered using cutting-edge, computer-based  
16 systems and networks. More conventional methods of information delivery (e.g., printed reports, workshops,  
seminars) will be used as appropriate. This will all be done with the goal of informing all those having an interest in  
ORD's mercury research.

19

## 6. REFERENCES

- 1
- 4 Agency for Toxic Substances and Disease Registry. (1999) *Toxicology Profile for Mercury*. (Atlanta, GA: ATSDR).
- 7 Arctic Council. (1991) *Arctic Environmental Protection Strategy*. (Rovaniemi, Arctic Environment, Arctic Council).  
<http://www.borealis.lib.uconn.edu/ArcticCircle/NatResources/>
- 10 CALFED. (1999) CALFED Bay – Delta Program.. (Sacramento, CA: CALFED). <http://calfed.ca.gov/>
- 13 Commission on Environmental Cooperation (CEC). (1998) *The Sound Management of Chemicals Initiative under the North American Agreement on Environmental Cooperation: Regional Commitments and Action Plans*, North American Commission for Environmental Cooperation. (Montreal (Quebec), Canada: CEC). <http://www.cec.org>
- 16 Environmental Protection Agency. (1996) *ORD's Strategic Plan (EPA /600/-96/059)*. (Washington, DC: EPA).
- 19 Environmental Protection Agency. (1997a) *Mercury Study Report to Congress (Vols. I – VIII) (EPA-452/R-97-003 through EPA-452/R-97-010)*. (Washington, DC: EPA). <http://www.epa.gov/oar/mercury.html>
- 22 Environmental Protection Agency. (1997b) *Deposition of Air Pollutants to the Great Waters: Second Report to Congress (EPA-453/R-97-011)*. (Washington, DC: EPA).
- 25 Environmental Protection Agency. (1997c) *The Great Lakes Binational Toxics Strategy: Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes*. (Chicago, IL: GLNPO).  
<http://www.epa.gov/glnpo/p2/bns.html>
- 28 Environmental Protection Agency. (1997d) *1997 Update to ORD's Strategic Plan (EPA/600/R-97/015)*. (Washington, DC: EPA). <http://www.epa.gov/ORDWebPubs/stratplan/>
- 31 Environmental Protection Agency. (1997e) *EPA Strategic Plan (EPA/190-R-97-002)*. (Washington, DC: EPA).  
[Http://epa.gov/ocfopage/strategic\\_plan/epastrat.pdf](Http://epa.gov/ocfopage/strategic_plan/epastrat.pdf)
- 34 Environmental Protection Agency. (1998a) *Clean Water Action Plan: Restoring and Protecting America's Waters (EPA-840-R-98-001)*. (Washington, DC: EPA). <http://cleanwater.gov/action/toc.html>
- 37 Environmental Protection Agency. (1998b) *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units -- Final Report to Congress (EPA-453/R-98-004a and b)*. (Washington, DC: EPA)  
<http://www.epa.gov/airlinks/>
- 40 Environmental Protection Agency. (1998c). *Pollution Prevention Research Strategy (EPA/600/R-98/123)*. (Washington, DC: EPA) 1998. <http://www.epa.gov/ORD/WebPubs/final>
- 43 Environmental Protection Agency. (1998d). *Ecological Research Strategy (EPA/600/R-98/086)*. (Washington, DC: EPA). <http://www.epa.gov/ORD/WebPubs/final>
- 46 Environmental Protection Agency. (1999a) *National: Listing of Fish and Wildlife Advisories -- 1998*. (Washington, DC: EPA). <http://www.epa.gov/OST/fish>

1 Environmental Protection Agency. (1999b) *Summary of the 2000 Budget (EPA205-S-99-001)*. Washington, DC: EPA). [Http://www.epa.gov/ocfopage/2000bib.pdf](http://www.epa.gov/ocfopage/2000bib.pdf)

4 Environmental Protection Agency. (1999c) *Third Great Waters Report to Congress (DRAFT)* (Washington, DC: EPA).

7 Environmental Protection Agency. (1999d) *U. S. Status Report of Mercury Activities (DRAFT)* (Washington, DC: EPA).

10 Federal Register. (1998) *A Multimedia Strategy for Priority Persistent, Bioaccumulative, and Toxic (PBT) Pollutants*. (Vol. 63: No. 221: 63926 – 63928, November 17, 1998). <http://www.epa.gov/pbt>

13 Lindberg (1995) "Workshop on sampling mercury in precipitation for the national Atmospheric Deposition Program," *Atmospheric Environment*: (Vol. 29, pp. 1219 -- 1220).

16 National Science Foundation .(1999) *United States Arctic Research Plan (DRAFT)* (Washington, DC: NSF).

19 Northeastern States for Coordinated Air Use Management (NESCAUM ).(1998) *Northeastern States and Eastern Canadian Provinces Mercury Study: A Framework for Action*. Boston, MA: NESCAUM,). <http://www.nescaum.org>

22 Office of Solid Waste – Environmental Protection Agency. (1998) *Analysis of Current Mercury Waste Generation and Management (Unpublished)*. (Washington, DC: Office of Solid Waste -- EPA).

25 Pirrone, Nicola, et. al. "Regional differences in worldwide emissions of mercury to the atmosphere.," *Atmospheric Environment*, Vol. 30, No. 17, pp. 2981-2987.

28 Schroeder, et.al. "Depletion of mercury vapor in the Arctic troposphere after polar sunrise.," in *Proceedings of the EUROPTAC - 2 Symposium on Transport and Chemical Transformation in the Troposphere*, (Garmisch-Partenkirchen, Germany, March 23 -- 27, 1998)

31 United Nations Economic Commission for Europe (UNECE). (1998) *The 1998 Aarhus Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution (LRTAP) on Heavy Metals*,(Aarhus, The Netherlands, UNECE). <http://www.unece.org/env/protocol/98hm.htm>.

34 World Health Organization/International Programme for Chemical Safety, (1991) *Criteria Document on Methylmercury* (Geneva, Switzerland, WHO).

37 Yeardeley, et.al. "Elemental fish tissue contamination in Northeastern U.S. lakes: evaluation of an approach to regional assessment," *Environmental Toxicology and Chemistry*, 17(9), pp. 1875-1884, 1998.

40

1

**APPENDIX 1:**

4

**MERCURY RESEARCH AREAS RELATED TO PROGRAM OFFICE COMMITMENTS**

1

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p data-bbox="94 359 116 392">4</p> <p data-bbox="94 468 116 501">7</p> <p data-bbox="94 577 116 611">10</p> <p data-bbox="94 686 116 720">13</p> <p data-bbox="94 795 116 829">16</p> <p data-bbox="203 323 483 747"><b>Key Scientific Question #1 (Human Health):</b> <i>What critical changes in human health are associated with exposure to environmental sources of methylmercury in the most susceptible human sub-population? in environmental releases from United States sources?</i></p>	<p data-bbox="516 323 841 392">Understanding Mechanisms of Developmental Neurotoxicity</p> <p data-bbox="516 426 846 495">Risk Assessment Uncertainties Due to Compensation</p> <p data-bbox="516 529 870 627">Risk Assessment Uncertainties Following Aggregate Exposure to Developmental Neurotoxins</p> <p data-bbox="516 661 878 730">Understanding Immunotoxicology of Mercury and Methylmercury</p>	<p data-bbox="906 323 1409 392">Regulatory Determination for Mercury Controls for Utilities</p> <p data-bbox="906 426 1377 495">Revision of the Human Health Water Quality Criterion for Mercury</p> <p data-bbox="906 529 1365 598">Revisions of Land Disposal Restrictions for Mercury-Bearing Hazardous Wastes</p> <p data-bbox="906 632 1325 701">EPA assistance to numerous State fish advisory programs</p> <p data-bbox="906 735 1398 804">Determination of Superfund cleanup levels for mercury</p>

19

1

4

7

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p><b>Key Scientific Question #2 (Ecological Systems):</b> <i>What are the risks associated with methylmercury exposure to valued wildlife species and other significant ecological receptors?</i></p>	<p>Toxicity of Methylmercury to Avian and Mammalian Wildlife</p> <p>Wildlife Risk Assessment Methods</p> <p>Ecological Impacts of Mercury on Avian and Mammalian Wildlife</p> <p>Impacts of Fish Non-Avian, Non-Mammalian Ecological Receptors</p> <p>Multiple Stressor Interactions</p>	<p>Wildlife criteria for mercury in the Great Lakes Basin.</p> <p>Potential future development of national wildlife criteria for mercury.</p> <p>Site-specific assessments of mercury impacts.</p>

10



Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p>1</p> <p>4</p> <p>7</p> <p>10</p> <p>13</p> <p>16</p> <p>19</p> <p>22</p> <p><b>Key Scientific Question #3 (Transport, transformation, and fate):</b> <i>How much methylmercury in fish consumed by the U.S. population is contributed by U.S. emissions relative to other sources of mercury (such as natural sources, emissions from sources in other countries, and re-emissions from the global pool); how much and over what time period, will levels of methylmercury in fish in the U.S. decrease due to reductions in environmental releases from United States sources?</i></p>	<p>Atmospheric Fate, Transport and Transformation</p> <p>Aquatic and Terrestrial Fate, Transport and Transformation</p> <p>Monitoring and Atmospheric Deposition</p> <p>Monitoring of Mercury in Fish</p>	<p>Incorporate mercury transport process model in the Community Model for Air Quality (CMAQ)</p> <p>Complete operational evaluation of Models-3/CMAQ for mercury.</p> <p>Complete mercury bioaccumulation model for aquatic systems and apply it to the Everglades Assessment (</p> <p>Design and begin operation of continuous monitoring system for atmospheric/terrestrial gaseous mercury flux in the Everglades</p> <p>Begin operation of wet deposition monitor in Ohio Valley</p> <p>Survey of Chemical Contaminants in Fish Tissue to provide a statistically representative sample of mercury levels as well as other contaminants in fish tissue.</p>

1

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p data-bbox="203 289 479 359"><b>Key Scientific Question #4 (Human Exposure):</b></p> <p data-bbox="203 363 487 783"><i>How much methylmercury are humans exposed to, particularly what are the exposures of women of child-bearing age and children among highly-exposed population groups; what is the magnitude of uncertainty and variability of mercury and methylmercury toxicokinetics in children?</i></p>	<p data-bbox="513 289 885 359">Monitoring of Highly Exposed Sub-population</p> <p data-bbox="513 390 885 491">Development of Toxicokinetic Data for Tissue Distribution of Methylmercury in Young Children</p>	<p data-bbox="943 289 1380 426">Analyses of hair and blood samples for mercury as part of the Fourth National Health and Nutrition Examination Survey (NHANES)</p>

4

7

10

13

16

1  
4  
7  
10  
13  
16

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p><b>Key Scientific Question #5 (Risk Management for Combustion Sources):</b> <i>How much can mercury emissions from coal-fired utility boilers and other combustion systems be reduced with innovative mercury control technologies; what is the relative performance and cost of these new approaches compared to currently available technologies?</i></p>	<p>Parameters Affecting Mercury Speciation and Improved Sorbents</p> <p>Performance and Cost of Specialized Sorbents, Reagents and Control Equipment</p> <p>Performance of Continuous Emissions Monitors to Measure total and Speciated Mercury in Low Concentrations</p> <p>Stabilization of Pollution Control System Residuals</p>	<p>Discussions on utility boiler emissions regulations (OAR)</p> <p>Mercury emissions limits for waste combustors. Evaluating compliance with these limits (OSW, Regions)</p> <p>CWAP goal of ensuring that fish and shellfish are safe to eat (OW)</p> <p>Urban Air Toxics Strategy</p> <p>State and regional mercury emissions reduction programs (OAR, Regions)</p> <p>Develop recommendations to limit emissions from additional combustion source categories (OAR)</p>

1  
4  
7  
10  
13

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p><b>Key Scientific Question #6 (Risk Management for Non-combustion Sources):</b> <i>What is the magnitude of contributions of mercury releases from non-combustion sources; how can the most significant releases be minimized?</i></p>	<p>Chlor-Alkali Industry Waste Disposal and Recycling Other Sectors Utilizing Mercury Contaminated Sediments and Soils Mining</p>	<p>Pursue voluntary reductions in industrial use and release (OPPTS, Regions I and V)</p> <p>GLWQA's goal that PBTs be virtually eliminated from Great Lakes</p> <p>North American Regional Action Plan promotion of "best practices" to minimize Mercury releases</p> <p>GLWQA's goal that PBTs be virtually eliminated from Great Lakes</p> <p>Revisions of Land Disposal Regulations (OSW)</p> <p>CWAP goal of ensuring that fish and shellfish are safe to eat (OW)</p> <p>Develop options addressing abandoned mines mercury problems (Region IX, OW)</p>

1

4

7

10

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
<p><b>Key Scientific Question #7 (Risk Communication):</b> <i>How does EPA effectively inform members of susceptible sub-populations of the health risks posed by mercury and methylmercury contamination of fish and seafood?</i></p>	<p>Monitoring data describing the distribution of mercury and methylmercury concentrations in fish</p> <p>Methods development for risk communication with women of child-bearing age from ethnically diverse groups</p>	<p>Revision of the Human Health Water Quality Criterion for Mercury</p> <p>EPA assistance to numerous states' fish advisory programs</p> <p>Determination of Superfund clean up levels for mercury</p>

13