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Mercury Research Strategy

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FOREWORD

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

The 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 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.

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 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 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.

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PEER REVIEW

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

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ACRONYMS

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

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

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*.

THE REASONS FOR A MERCURY RESEARCH STRATEGY

Based on the global nature of the mercury 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 management options, ORD senior management identified mercury as a priority 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.

EPA's Program Office commitments related to mercury must be met over the coming five to ten years (Table 1). One of the most important commitments is the Office of Air and Radiation's (OAR's) mandates under the Clean Air Act (as amended in 1990), with particular emphasis on 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 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.

Mercury is recognized internationally as an important pollutant that warrants collaborative study and action. The Office of Prevention, Pesticides, and Toxic Substances (OPPTS) and GLNPO are undertaking voluntary efforts to remove mercury from wastes, products, and processes, with a goal of a 50 % reduction by the mid-2000s under 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.

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

Program Office/Region	Regulatory Activities	Fiscal Year Target Date
Office of Air and Radiation		
Settlement Agreement on Utility Regulation Maximum Achievable Control Technology (MACT) Standards • Industrial Combustion Coordinated Rulemaking (ICCR) • Chlor-Alkali Facilities • Landfills Integrated Urban Air Toxics Strategy	Publish Urban Air Toxics Strategy	1999
	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
Office of Water		
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
Office of Solid Waste and Emergency Response		
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

RESEARCH CATEGORIES AND KEY SCIENTIFIC QUESTIONS

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

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 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:

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 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 deciding when fish consumption advisories are needed to protect public health from mercury pollution. The key scientific questions are:

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

Mercury Transport, Transformation, and Fate

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 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 sources having the greatest impact on a particular ecosystem. The key scientific question is:

> ***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?*

Human Exposure to Methylmercury Through the Aquatic Food Chain

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 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

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

> ***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?*

Risk Management of Mercury and Methylmercury

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 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 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 standards or voluntary reduction targets that have been negotiated with EPA and the international community. The key scientific questions are:

> ***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?*
>
> ***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?*
>
> ***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?*

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.

Research Priorities and Emphases

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 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 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,

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 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.

RESEARCH STRATEGY FORMAT AND AUDIENCE

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, 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:

- 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 methylmercury impacts in children and other susceptible sub-populations, releases from coal-fired utility boilers and other combustion and non-combustion sources, and effective 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.

- 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.

- 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.

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.

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 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 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.

1. INTRODUCTION

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[1]. 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[2]. 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.

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.

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

[1] 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).

[2] 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.

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 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. 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.

1.1 MERCURY EMISSIONS AND RELEASES

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 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 metals, as an antifungal agent in wood preserving, and as a solvent for reactive and precious metals (EPA, 1997a).

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 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 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 demand.

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") (EPA, 1997a)[3]. 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 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 as an impurity. Anthropogenic mercury sources within the United States emit approximately

[3] 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).

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

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

> *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)[4]. 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).

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. 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 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 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).

1.2 MERCURY TRANSPORT, TRANSFORMATION, AND FATE

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, 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 their significance as contaminants, resulting in:

[4] 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).

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

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.

Global scale impacts, which result from Hg^0 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).

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.

1.3 IMPACTS OF METHYLMERCURY ON HUMAN AND WILDLIFE HEALTH

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

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 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 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 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 sufficient amounts of fish for their fetuses to be at risk from methylmercury exposure, depending on the methylmercury concentrations in the fish.

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)[5]. 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, 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 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 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 and piscivorous mammals in their diets (e.g., some Alaskan native groups).

[5]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.

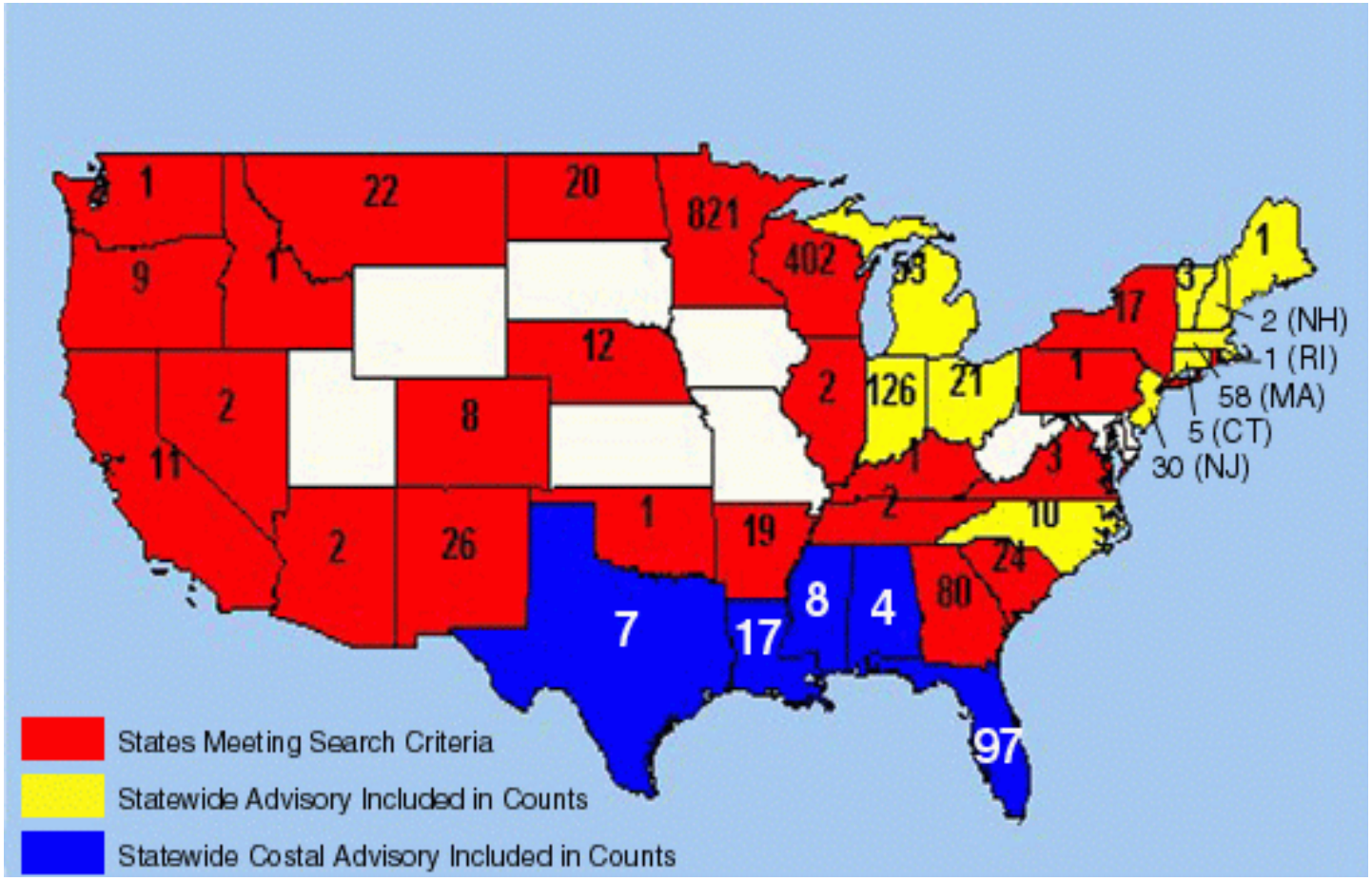

Figure 2. Mercury-based fish consumption advisories for the United States, December 1998 (EPA, 1999a).

1.4 MERCURY RISK MANAGEMENT OPTIONS

> *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

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.

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 methlymercury in fish consumed by the United States population, the variability in

methylmercury impacts in children and other susceptible sub-populations, releases from coal-fired utility boilers and other combustion and non-combustion sources, and effective 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.

- 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.

- Chapter 5.0 identifies issues beyond research that deserve attention and are supportive of 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 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.

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
Office of Air and Radiation		
Settlement Agreement on Utility Regulation Maximum Achievable Control Technology Standards • Industrial Combustion Coordinated Rulemaking (ICCR) • Chlor-Alkali Facilities • Landfills Integrated Urban Air Toxics Strategy	Publish Urban Air Toxics Strategy	1999
	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
Office of Water		
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
Office of Solid Waste and Emergency Response		
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

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 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 terms of the assessment of risks to humans and wildlife and the characterization and management of risks from sources.

2.2 INTERNATIONAL OPPORTUNITIES TO ADDRESS MERCURY

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 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 international programs addressing mercury are:

- 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);
- 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);
- The North American Commission on Environmental Cooperation (NACEC), specifically its North American Regional Action Plans (NARAP) (Canada, Mexico, and the United States) (CEC, 1998);
- 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 States) (EPA, 1997c); and
- The *Northeastern States and Eastern Canadian Provinces Mercury Study: A Framework for Action* (NESCAUM,, 1998)

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.

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

Program Office/Region	Multi-national Provisions	Target Date
Office of Air and Radiation		
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
Office of Air and Radiation & Office of Research and Development		
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
Office of International Activities, Office of Research and Development, & Region 10		
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
Office of Prevention, Pesticides, and Toxic Substances		
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
Region 5; GLNPO; OPPTS; all EPA Offices		
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
Region I; all EPA Offices		
The NE Governors-Eastern Canadian Premiers Mercury Action Plan (June 1998)	Virtual elimination of anthropogenic discharge of mercury	2003
	Progress Report	1999

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

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

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 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 for investment in FY 2000.

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 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).

3. MERCURY RESEARCH STRATEGY GOAL AND PRIORITIES

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 research into documents that can be used to inform future decisions by

GOAL

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

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-objective under Goal 8's Emerging Risks Objective (8.3).

3.1 KEY SCIENTIFIC QUESTIONS AND RESEARCH AREAS

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.

3.1.1 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. The key scientific questions and planned research areas are:

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?*

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

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

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.

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

- ❑ 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.

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

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:

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?*

- ❑ 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., $HgCl_2$).

- ❑ 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

monitoring program.

Results from this research will provide an improved understanding of the environmental fate and transport of mercury 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 then 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.

3.1.3 Human Exposure to Methylmercury through the Aquatic Food Chain

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:

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?*

- ❑ 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.

- ❑ Establish kinetic patterns of methylmercury distribution in children following ingestion of methylmercury from dietary sources.

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 and will also apply the results to identify source categories where reductions have had, or will have, the greatest impact on risk reduction.

3.1.4 Risk Management of Mercury and Methylmercury

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:

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?*

- ❑ 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.

- ❑ 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 the species of mercury in combustion systems.

- ❑ 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.

- ❑ 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).
- ❑ Estimate the capital and operating costs of various mercury control options.
- ❑ Characterize the stability (leachability and volatility) of air pollution control device mercury residuals and evaluate any necessary options to stabilize these residuals.

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?*

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

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?*

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

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.

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

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:

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

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 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 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.

3.3 SETTING PRIORITIES FOR MERCURY RESEARCH

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 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 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 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), the more qualitative they become. The rationale for emphasis trends for each of the key scientific questions follows:

3.3.1 Human Health

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 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.

3.3.2 Ecological Systems

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)[6] will predominate in FY2000 but will be replaced by a growing need for ecological research in later years. 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 Grants Program will also contribute.

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 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 supplemented by projects under the STAR Grants Program..

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 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.

[6] 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).

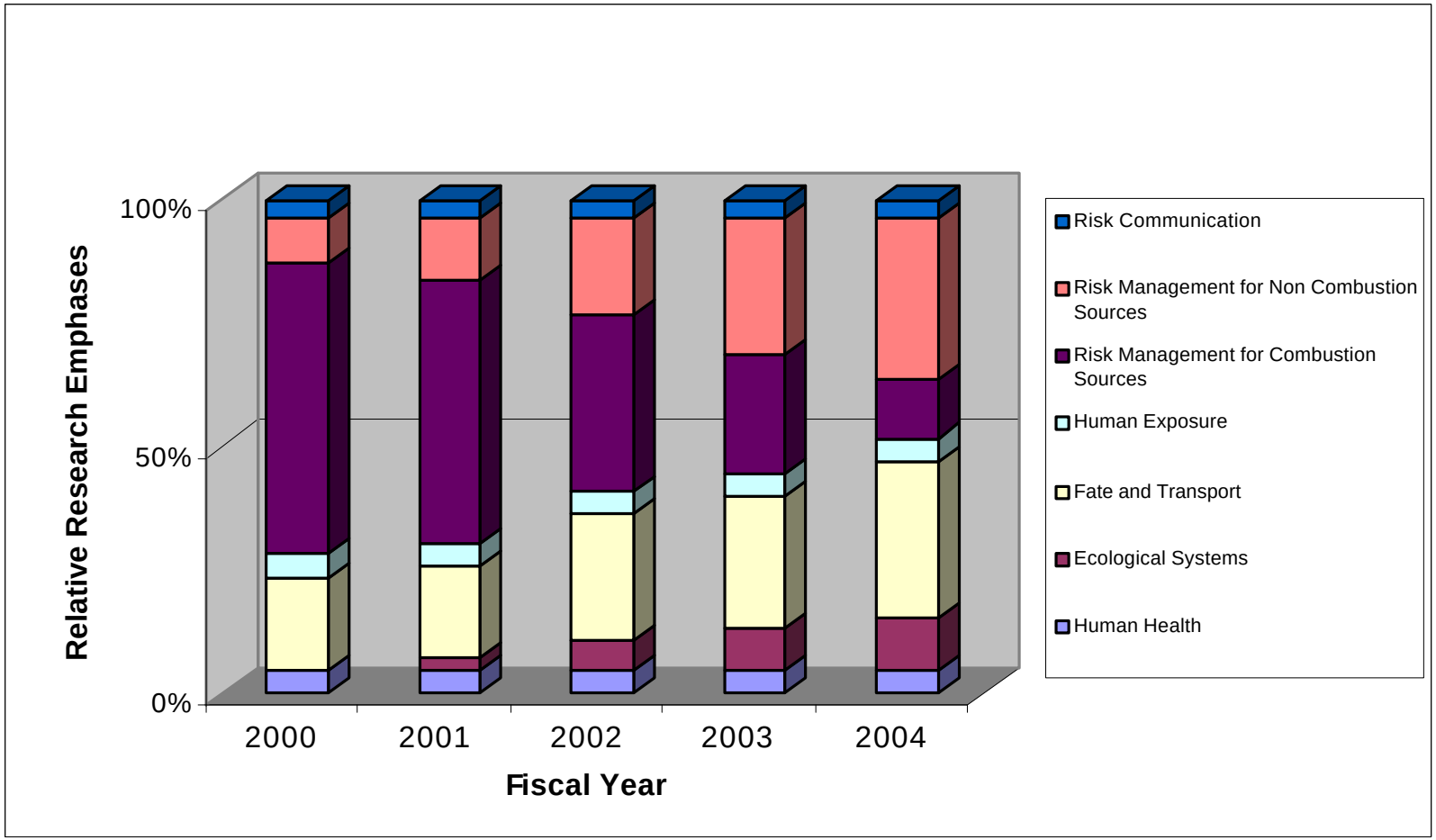

Figure 3. Research emphases for *Mercury Research Strategy* key scientific questions (FY 2000 -- FY 2004).

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

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.

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 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 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 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 assist in achieving the goal of the *Mercury Research Strategy*.

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. 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 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 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 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.

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 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 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 is the establishment of a coordinated research program for the investigation of ecological processes in the field and the collection of environmental data for model development and

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.

3.4.3 Human Exposure to Methylmercury Through the Aquatic Food Chain

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 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.

3.4.4 Risk Management of Mercury and Methylmercury

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 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 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 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 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.

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 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 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.

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 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 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 specific (e.g., risks of exposure to lead or to radon). Funding sources for such work vary with the disease or agent.

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 diseases and injuries.

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. 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 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.

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 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 effecting the Great Waters of the United States (e.g., Great Lakes, Chesapeake Bay); (3) the National Estuarie 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) 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 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 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 methlymercury 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 μg/kgbw/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 μg/kg by weight basis) of the young

child. If research subsequently demonstrates that immunotoxiocity 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 immunotoxiocity.

4.1.1.3 Prioritized Research Needs.

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 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-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 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 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 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 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).

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 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 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, 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 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.

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 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 characterize the neurotoxicity and immunotoxicity of aggregate exposures.

Understanding Imunotoxicology 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), and allergy. Specific research findings in these areas include:

- *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.

- *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 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.

- *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 demonstrated in adults and children. There is, however, little clear evidence to date of age-related sensitivity either qualitatively or quantitatively.

These findings raise the following questions:

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?

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 (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 scientifically possible to set a level of exposure below which mercury-related symptoms will not occur. This observation raises research questions, including the following:

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 process?

4.1.2 Measures of Success

Researchers hope to obtain the following:

- 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.

- An improved determination as to whether young children or maternal-fetal pairs are the

subpopulation at greatest risk from methylmercury exposures.

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

4.2 ECOLOGICAL SYSTEMS

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

4.2.1.1 Background.

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.

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."

4.2.1.2 Program Relevance.

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.

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

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

4.2.1.3 Prioritized Research Needs.

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.

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 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 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, 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.

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 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 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 replaced by information that would permit the calculation of effects benchmarks and statistical confidence limits.

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 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 bioaccumulation models for fish must be developed to provide probabilistic residue estimates within and among trophic levels.

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 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 mercury contamination? (2) Do field data support projections of increased risk to wildlife living in proximity to mercury

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 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 contribute to the demise of endangered wildlife species.

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 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 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 relationships, experience mercury exposure comparable to that of piscivorus wildlife.

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 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 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.

4.2.2 Measures of Success

Researchers hope to obtain the following:

- Successful characterization of the toxicokinetics and toxicodynamics of methylmercury in piscivorous avian and mammalian wildlife.
- Development of probabilistic ecological impact assessment procedures for mercury that explicitly recognize relevant natural processes.
- Characterization of the impact of methylmercury on piscivorous wildlife populations at local, regional, and national scales.
- Reduction in the uncertainty in evaluation of potential adverse effects on fish.
- 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

stressors.

4.3 FATE AND TRANSPORT

4.3.1 Key Scientific Question #3:

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?

4.3.1.1 Background.

Mercury bioaccumulates most efficiently in the aquatic food web. Predatory organisms at the top of the food web generally have higher methylmercury concentrations. Nearly all of the mercury that accumulates in fish tissue is methylmercury. Inorganic mercury, which is less efficiently absorbed and more readily eliminated from the body than methylmercury, does not tend to bioaccumulate. Fish consumption dominates the pathway for human and wildlife 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.

4.3.1.2 Program Relevance.

As methylmercury is the primary route of exposure to both humans and wildlife, it is critical to understand the relationship among its concentration of methylmercury in fish, levels of ambient mercury in the environment, and 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.

4.3.1.3 Prioritized Research Needs.

The key scientific question encompasses a number of subsidiary questions, including factors influencing 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

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 designs is better developed, so this category is deemed a medium-high priority.

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 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 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 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.

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 following scientific types of information are high- priority needs:

- 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 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, 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.

- 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 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 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. 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 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 source attribution issues in South Florida, particularly in distinguishing between local and global

sources.

- Short-range atmospheric transport models (range of 50 - 200 kilometers) to predict air concentrations and deposition. This modeling range is needed for many analyses, such as TMDL 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.

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:

- Information on the atmospheric fate of mercury species in various scenarios. In particular, little is 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 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.

- Information on transport mechanisms affecting cross-boundary pollution. For example, recent 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 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.

- Field-test results of a mercury measurement technology that has been developed to determine both 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 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 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.

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 200 kilometers) to be used in the development of emissions limits to protect water quality and public and ecological health.

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, 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 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 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 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.

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 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 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 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 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.

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 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 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. 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 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 migratory patterns and behavior of migratory fish, marine mammals, migratory birds and other species of importance in the food chan is needed.

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

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 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. 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 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 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.

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 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 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 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 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 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

Researchers hope to obtain the following:

- Measurable improvement in the scientific understanding of the linkage between fish methylmercury, ambient mercury in the environment, and emissions.
- Completion of a national sampling plan for methylmercury and other persistent chemicals in fish tissue.
- 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.
- Completion of a multimedia integrated modeling system capable of quantifying regional exposure to mercury.

4.4 HUMAN EXPOSURE

4.4.1 Key Scientific Question #4: *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?*

4.4.1.1 Background.

Consumption of fish and of marine birds and mammals represents more than 95 % of the human intake of methylmercury. Within the United States, individual consumption of fish/seafood is highly variable. Approximately 1% to 2% of the U.S. population report eating fish daily, whereas about 10% rarely consume fish. The *Mercury Study Report to Congress* (1EPA, 997a) conducted extensive analyses of fish consuming habits/patterns among the general U.S. population and high-risk sub-populations. To improve the human-exposure estimate on the basis of 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.

4.4.1.2 Program Relevance.

Estimating the size of the "at risk" human population for methylmercury exposure requires data on how much methylmercury people consume from fish/seafood. Data on geographically determined variability in the concentrations of methylmercury in fish/seafood are critical to estimating local impacts of control technologies and 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.

4.4.1.3 Prioritized Research Needs.

Monitoring of highly exposed human sub-populations. There is a need to conduct biological monitoring of sub-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)

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 ingested in diverse temporal patterns.

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.

4.4.2 Measures of Success

Researchers hope to obtain the following:

- Measurable improvement in the scientific understanding of the variability in fish/methylmercury consumption among the most highly exposed sub-populations in the United States.
- 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.

4.5 RISK MANAGEMENT FOR COMBUSTION SOURCES

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 currently available technologies?*

4.5.1.1 Background.

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).

4.5.1.2 Program Relevance.

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 implemented, and standards proposed by the Office of Solid Waste (OSW) for hazardous waste incinerators (HWIs)

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

4.5.1.3 Prioritized Research Needs.

Over the next three to five years, ORD will work cooperatively with DOE, USGS, and private sector organizations including EPRI to address the key scientific questions above. Studies will be conducted to identify, evaluate, and demonstrate innovative technological solutions that can cost-effectively reduce mercury emissions where standards have not been issued or where improved technologies would significantly reduce the costs to comply with existing regulations. The selection of mercury emission control methods is driven by both performance and cost considerations. Sorbents that have improved performance for both ionic and elemental forms of mercury need to be investigated. The relative costs of controlling only mercury and of controlling mercury in conjunction with other pollutants such as fine particulate matter (PM) and fine PM precursors (SO_2 and NO_x) also need to be quantified.

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

Determine the parameters that affect mercury species emitted from combustion systems and identify potential approaches to capture these species. In combustion systems, mercury is volatilized and converted to elemental mercury (Hg^0) in the high-temperature regions of furnaces. As the flue gas is cooled, mercury is oxidized to ionic forms (Hg^{++}). The rate of oxidization is dependent on the temperature, flue gas composition, and the amount and properties of entrained particles (fly ash and sorbents). Hg^0 and $HgCl_2$ are in the vapor phase at flue-gas cleaning temperatures, and special methods must be used for their capture. Each of these forms of mercury can be adsorbed onto porous solids such as fly ash, powdered activated carbon, and calcium-based acid-gas sorbents for subsequent collection in a PM control device. These mercury compounds can also be captured in carbon bed filters or other reactors containing appropriate sorbents. In the United States, the control of mercury in MWCs and MWIs is based on the injection of powdered activated carbon upstream of an electrostatic precipitator or fabric filter. $HgCl_2$ is water soluble and readily reacts with alkali metal oxides in an acid-base reaction; therefore conventional acid gas scrubbers used for SO_2 control are effective in controlling $HgCl_2$. Hg^0 is insoluble in water and must be adsorbed onto a sorbent or converted to a soluble form that can be collected in a wet scrubber. Ionic mercury also has low solubility and must be controlled by methods similar to those used for Hg^0.

In incinerators, the flue-gas concentration of chlorine, in the form of hydrogen chloride (HCl), is substantially higher than the concentration of Hg^0. In these cases, Hg^0 is preferentially converted to mercuric chloride ($HgCl_2$). In

coal-fired combustors, where the concentrations of HCl are much lower and SO_2 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^0 to the easier-to-capture $HgCl_2$. 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).

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.

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^0 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

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 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.

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 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 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.

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 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.

4.5.2 Measures of Success

Researchers hope to obtain the following:

- Identification of the combustion conditions that have the most significant impact on the species of mercury formed in coal-fired utility boilers
- On the basis of the above information, design innovative control systems for testing at a larger scale.
- Identification and field evaluation of improved devices to measure both total mercury and species of mercury.
- Successful demonstrations, at full-scale, of innovative options (including performance and cost) to reduce mercury emissions from coal-fired utility boilers.
- 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.

4.6 RISK MANAGEMENT FOR NON-COMBUSTION SOURCES

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?*

4.6.1.1 Background.

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

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 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 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, 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.)

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 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 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.

4.6.1.2 Program Relevance.

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 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.

4.6.1.3 Prioritized Research Needs.

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 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 "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 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 categories; and (4) international transfer of technologies for reducing the use and release of mercury.

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

non-combustion sources). The U.S. chlor-alkali industry's average annual mercury usage for the period 990 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 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 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 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.

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 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 environment from some facility processes. Improved approaches are particularly needed to characterize mercury releases from cell rooms.

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 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 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 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 effective techniques for characterizing and reducing those emissions.

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), 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 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 manufacturing process redesign, raw materials substitution, or other technologies that would reduce the amount of mercury found in hazardous waste.

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

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 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. 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 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.

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 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. 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. 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 metals. Source reduction is a principal component of all these activities.

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 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. 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. 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 research in this area.

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 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 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.

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 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. 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 and RCRA Corrective Action programs; ORD is not aware of any special efforts in EPA to address the remediation of mercury-contaminated soils.

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 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 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.

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 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 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 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 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 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 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.

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 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 about 2001. Such research would investigate new, low-cost management methods needed to control mercury

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 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.

4.6.2 Measures of Success

Chlor Alkali Industry Releases

Researchers hope to obtain the following:

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

Waste Disposal

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

Other Sectors

- Assessment of mercury use in the consumer sector to identify major needs and opportunities for reduced use and/or releases.
- 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

- 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.
- Evaluation of the bench-scale approaches to sequestration or separation of mercury from contaminated sediments.

Mining

- Identification of waste types that contribute most to mobile mercury.
- 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*

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

4.7.1.1 Background.

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

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

4.7.1.2 Program Relevance.

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

4.7.1.3 Prioritized Research Needs.

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

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

4.7.2 Measures of Success

Researchers hope to obtain the following:

- Mapped distribution of mercury levels in fish found in all waterways in the United States.

- Identification of the risk communication styles utilized by women of childbearing age from ethnically diverse populations.

- 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.

- Development of fish advisories of proven effectiveness that reach 90% of the at-risk population.

- 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:

<u>Air medium</u>

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

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

Non-air media

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

Biota

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

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.

5.2 ENGAGEMENT AND PARTNERSHIP

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.

5.3 RESEARCH PRODUCT DELIVERY AND UTILIZATION OF RESEARCH RESULTS

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

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 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. 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.

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 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 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.

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APPENDIX 1:

MERCURY RESEARCH AREAS RELATED TO PROGRAM OFFICE COMMITMENTS

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
Key Scientific Question #1 (Human Health): *What critical changes in human health are associated with exposure to environmental sources of methlymercury in the most susceptible human sub-population? in environmental releases from United States sources?*	Understanding Mechanisms of Developmental Neurotoxicity Risk Assessment Uncertainties Due to Compensation Risk Assessment Uncertainties Following Aggregate Exposure to Developmental Neurotoxins Understanding Imunotoxicology of Mercury and Methylmercury	Regulatory Determination for Mercury Controls for Utilities Revision of the Human Health Water Quality Criterion for Mercury Revisions of Land Disposal Restrictions for Mercury-Bearing Hazardous Wastes EPA assistance to numerous State fish advisory programs Determination of Superfund cleanup levels for mercury

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

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
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 due to reductions in environmental releases from United States sources?*	Atmospheric Fate, Transport and Transformation Aquatic and Terrestrial Fate, Transport and Transformation Monitoring and Atmospheric Deposition Monitoring of Mercury in Fish	Incorporate mercury transport process model in the Community Model for Air Quality (CMAQ) Complete operational evaluation of Models-3/CMAQ for mercury. Complete mercury bioaccumulation model for aquatic systems and apply it to the Everglades Assessment (Design and begin operation of continuous monitoring system for atmospheric/terrestrial gaseous mercury flux in the Everglades Begin operation of wet deposition monitor in Ohio Valley Survey of Chemical Contaminants in Fish Tissue to provide a statistically representative sample of mercury levels as well as other contaminants in fish tissue.

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
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?*	Monitoring of Highly Exposed Sub-population Development of Toxicokinetic Data for Tissue Distribution of Methylmercury in Young Children	Analyses of hair and blood samples for mercury as part of the Fourth National Health and Nutrition Examination Survey (NHANES)

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
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?*	Parameters Affecting Mercury Speciation and Improved Sorbents Performance and Cost of Specialized Sorbents, Reagents and Control Equipment Performance of Continuous Emissions Monitors to Measure total and Speciated Mercury in Low Concentrations Stabilization of Pollution Control System Residuals	Discussions on utility boiler emissions regulations (OAR) Mercury emissions limits for waste combustors. Evaluating compliance with these limits (OSW, Regions) CWAP goal of ensuring that fish and shellfish are safe to eat (OW) Urban Air Toxics Strategy State and regional mercury emissions reduction programs (OAR, Regions) Develop recommendations to limit emissions from additional combustion source categories (OAR)

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
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?*	Chlor-Alkali Industry Waste Disposal and Recycling Other Sectors Utilizing Mercury Contaminated Sediments and Soils Mining	Pursue voluntary reductions in industrial use and release (OPPTS, Regions I and V) GLWQA's goal that PBTs be virtually eliminated from Great Lakes North American Regional Action Plan promotion of "best practices" to minimize Mercury releases GLWQA's goal that PBTs be virtually eliminated from Great Lakes Revisions of Land Disposal Regulations (OSW) CWAP goal of ensuring that fish and shellfish are safe to eat (OW) Develop options addressing abandoned mines mercury problems (Region IX, OW)

Key Scientific Question	Associated Mercury Research Areas	Supported EPA Mercury Activities
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?*	Monitoring data describing the distribution of mercury and methyl mercury concentrations in fish Methods development for risk communication with women of child-bearing age from ethnically diverse groups	Revision of the Human Health Water Quality Criterion for Mercury EPA assistance to numerous states' fish advisory programs Determination of Superfund clean up levels for mercury