5.0 RESEARCH AREAS, KEY SCIENTIFIC QUESTIONS AND RESEARCH NEEDS

> ***Mercury Research Strategy Goal***
>
> To provide information and data that reduce scientific uncertainties limiting the Agency's ability to assess and manage mercury and methylmercury risks.

The *Mercury Research Strategy* was designed to identify areas where the Agency's knowledge and understanding of mercury can be improved. In preparing the *MRS*, six key scientific questions were identified that require ORD's attention. The answers to these questions will provide information and data to assist the Agency in assessing and managing mercury and methylmercury risks. This chapter describes the methodology used to identify the research areas and key scientific questions, and to prioritize research needs. It also includes a discussion of how the Agency is implementing research on the needs that were identified. Funding allocations are presented, as are the emphases for the mercury research program over the next five years. The chapter concludes with a detailed presentation of each of the six key scientific questions and associated research needs.

5.1 MERCURY RESEARCH PRIORITIES

5.1.1 Identification of Research Areas

The six research areas described in this *Mercury Research Strategy* were identified through an interactive process between the (ORD) and EPA's Program Offices and Regions. ORD consulted with its EPA customers and asked them to identify those areas in which a lack of scientific and technical knowledge and data related to mercury inhibited their ability to fulfill their missions. Input received from the Program Offices and Regions was categorized into broad research areas organized around the risk paradigm. The research areas identified were: Human Health Effects and Exposure; Ecological Effects and Exposure; Transport, Transformation, and Fate; Risk Management for Combustion Sources; Risk Management for Non-Combustion Sources; and Risk Communication. Writing teams comprised of ORD personnel and representatives from Program Offices and Regions were created to address each research area. The lead writers for each of these writing teams formed the *MRS* Writing Team.

5.1.2 Development of Key Scientific Questions

The key scientific questions identified for each research area were developed by the various writing teams. The questions were formulated, and re-formulated, as the writing process progressed. It was the goal of each of the writing teams to capture the key scientific questions (in some cases the key scientific question includes a series of inter-related sub-questions) in a way that allows for the development of long-term goals as part of the multi-year research implementation plan. These long-term goals are then translated into Annual Performance Goals (APGs) and Annual Performance Measures (APMs) in accord with the Government Performance and Results Act.

5.1.3 Prioritization of Research Areas and Key Scientific Questions

ORD, in consultation with its Program and Regional Office counterparts, established the priorities for the mercury research program. The prioritization process was influenced by an understanding of the regulatory and voluntary drivers facing the Agency (Chapter 3.0). International issues were integrated within each appropriate research area. In addition, the research areas were evaluated by the writing teams to determine the level of funding needed, while maintaining a viable portfolio of research across the six key scientific questions. Priorities are subject to re-evaluation and adjustment depending on a number of factors (*e.g.,* progress in answering the key scientific questions, influential regulatory deadlines, research by other organizations). These factors require that priorities and trends in emphasis be revisited on a year-to-year basis as part of ORD's annual planning process.

5.1.4 Identification of Research Needs

In identifying the research needs for the *Mercury Research Strategy*, the most influential resource was the *Mercury Study Report to Congress* because it contains an extensive analysis of the state-of-the-science understanding of mercury and methylmercury. Each writing team reviewed the research needs described in the *Report to Congress* across the risk paradigm (*i.e.,* human and ecological health effects; human and ecological exposures; transport, transformation and fate; and risk management for combustion and non-combustion sources). The writing teams then matched up research needs with the key scientific questions. ORD and the Office of International Activities (OIA) lead a cross-cutting team addressing international mercury issues.

5.1.5 Prioritization of Research Needs

The research needs under each research area were prioritized using the following criteria:

- Provide timely scientific information and data needed to inform current and future Agency decisions on mercury.
- Fill data and information gaps on mercury not addressed by other organizations.
- Support the goals and objectives of ORD's Strategic Plan (EPA, 1996; EPA, 1997b) which stress research in accord with the risk assessment/risk management paradigm.

ORD's overall research program covers a variety of topics. Some of the investigations underway as part of other research strategies may well contribute to advancing the mercury research program. A preliminary review of the *Ecological Research Strategy*, the *Pollution Prevention Research Strategy*, and the *Waste Research Strategy* (EPA, 1998c; EPA, 1998d; EPA, 1999b) indicates this possibility. Where pertinent scientific information and technical data are being developed under these or other ORD research strategies, resource leveraging will be explored and, when appropriate, employed. Where scientific information and technical data are being developed by other organizations (*e.g.,* USGS, DOE), ORD intends to work collaboratively with these organizations to convey their information and data to appropriate Agency decision-makers. The focus will be on work that complements ORD's efforts and is critical to fully addressing the six research areas.

5.1.6 Peer Panel Review of the *Mercury Research Strategy*

The last step in the prioritization process followed an external peer review of the draft *MRS* conducted on December 9 –11, 1999 in Washington, DC. Ten experts from outside EPA were assembled to review the draft *MRS* and offer their individual and collective opinions on the document. Because the *Mercury Research Strategy* extends across the risk management paradigm, the peer reviewers were selected based on their broad experience, expertise, and the various disciplines that they represented (from risk assessment through risk management). The *MRS* Writing Team was particularly interested in the opinions of the peer reviewers from an interdisciplinary perspective. The writing team wanted to be sure that the scientific issues around mercury and methylmercury were adequately addressed across all research areas. By and large, the peer panel found the priorities to be appropriate, but did recommend an increased emphasis on atmospheric transport, transformation, and fate of mercury. That recommendation and a number of other suggestions were incorporated into this final version of the *MR*S.

5.2 TAKING ACTION ON IDENTIFIED PRIORITIES

In order to achieve the *MRS* goal, ORD is undertaking and sponsoring research that addresses both mercury and methylmercury risk assessment and risk management questions. This research is being conducted by scientists and engineers in ORD laboratories and centers, at universities, by the private sector, and with other federal organizations. ORD plans to take the lead in integrating the results from this research into information that can be used to inform future decisions by the Agency's Program Offices and Regions. Research priorities identified in the *Mercury Research Strategy* will be used to guide decisions relating to ORD funding of in-house research, sponsored research, and collaborative mercury research efforts.

5.3 STRATEGIC DIRECTIONS

Mercury is a human and ecosystem risk and a high priority both within and outside of 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 Agency target dates. The *MRS* is designed to provide broad strategic directions for ORD's mercury research program in the coming five years. It is not intended to convey detailed information on specific projects. Specifics will be presented in a subsequent ORD mercury research multi-year implementation plan.

ORD's current emphases for the mercury research program from FY 2001 through FY 2005 appear below. This projection was made with an assumed stable funding level of $6.1M per year over that time period. This estimate incorporates funding from ORD's National Center for Environmental Research (NCER) that supports a research program on aquatic and terrestrial transport, transformation, and fate (Appendix A). Of the $6.1M, approximately $2.0M will be targeted toward the Science to Achieve Results (STAR) Grants Program and the remainder will be used to support in-house research activities. Funding projections for the six key scientific questions are presented in Figure 3, but could well change over the course of the coming years. The further into the future the projections go (*e.g.,* FY 2003 - 2005), the more uncertain they become. For each of the research areas, the rationale for the trends follow.

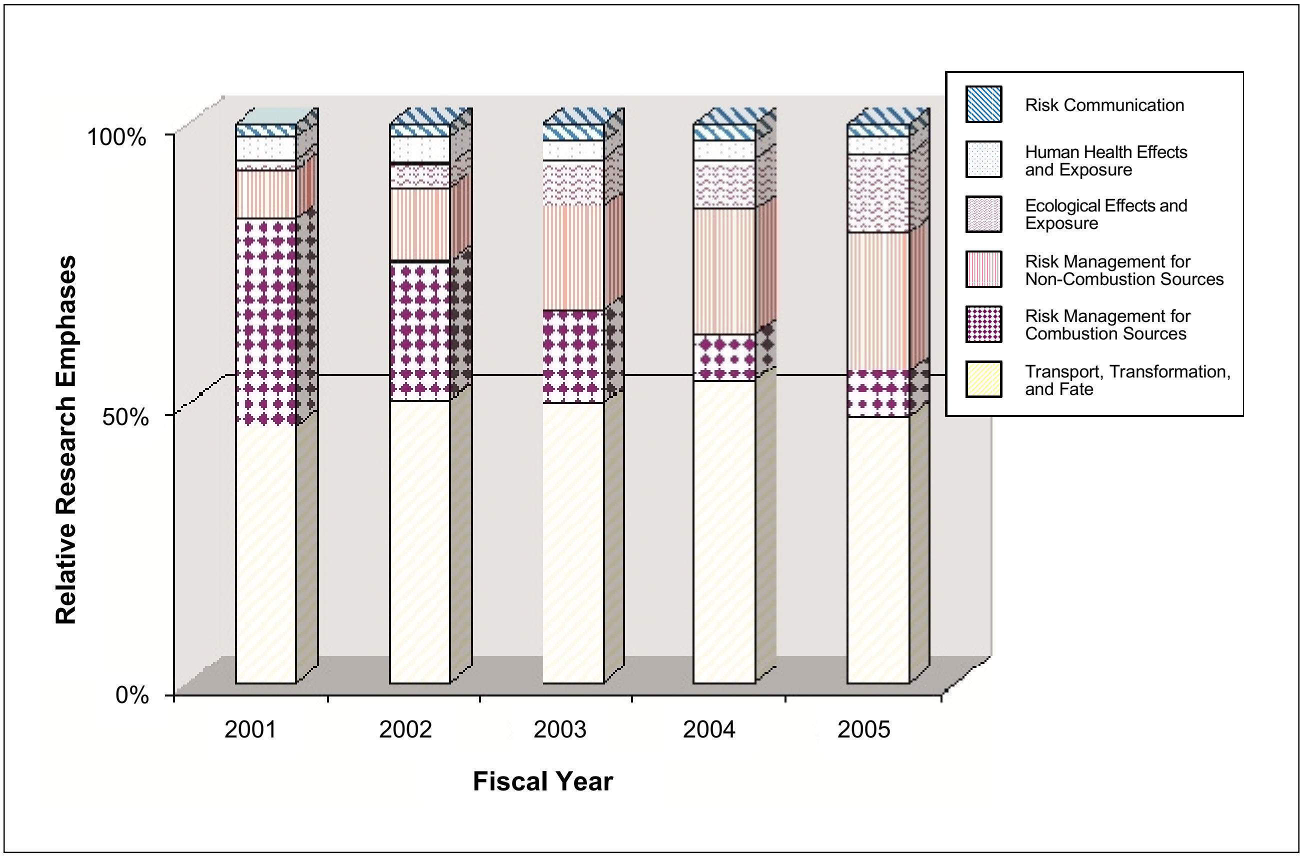

Figure 3. Research Emphases for *Mercury Research Strategy* Key Scientific Questions (FY 2001– FY 2005).

5.3.1 Transport, Transformation, and Fate

Research on mercury transport, transformation, and fate will fluctuate somewhat, but remain relatively stable through the FY 2001-2005 period. Answers regarding this research area will take some time to resolve because transport, transformation, and fate of mercury is so complex once it enters the environment. This research is considered a high priority and will allow an improved understanding of mercury in the environment in terms of any future regulatory efforts. Ultimately, such understanding will lead to more cost-effective risk management approaches for mercury and methylmercury. Expertise in ORD is available in the National Exposure Research Laboratory (NERL), but will be supplemented by a series of projects under the STAR Grants Program. (Refer to Appendix A for additional information.)

5.3.2 Risk Management for Combustion Sources

Research to manage risks from combustion sources addresses the highest near-term mercury priority and will require a significant proportion of the *MRS* budget from FY 2001 through FY 2003, with a gradual decrease thereafter. Combustion risk management research is needed to provide the Agency with the latest information on control technology performance and cost. This will support the development of an official regulatory proposal for coal-fired utilities by FY 2004. 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 DOE, USGS, and EPRI, to demonstrate the most promising technologies for managing mercury from combustion sources.

5.3.3 Risk Management for Non-Combustion Sources

Research to manage risks from non-combustion sources will be modest in FY 2001 and FY 2002, but then increase over the FY 2003-2005 time frame as the need for risk management research for coal-fired utilities decreases and other mercury sources become more prominent. The research will provide information to support future assessments, rulemaking, and voluntary actions with an early emphasis on source characterization. Expertise in source characterization and control technology for non-utility sources of mercury and methylmercury is available in NRMRL. Other federal agencies (*e.g.,* USGS, DOE) and private organizations (*e.g.,* the Chlorine Institute) must also be engaged.

5.3.4 Ecological Effects and Exposure

Research on the effects of methylmercury have been demonstrated in ecological systems (EPA, 1997a), but there is a need to learn more about its effects, particularly with respect to fish-eating wildlife. Ecological research will assist the Office of Water (OW) in the development of aquatic and wildlife water quality criteria and will gradually increase over the FY 2001-2005 period. This research will be split evenly between effects and assessment activities. Expertise is available within ORD for both types of research (National Center for Environmental Assessment - [NCEA] and National Health and Environmental Effects Research Laboratory - [NHEERL]), but research being conducted by other federal agencies such as the USGS and projects under the STAR Grants Program also contribute to ORD's efforts in this research area.

5.3.5 Human Health Effects and Exposure

The National Academy of Sciences (NAS) report on the health effects of methylmercury supported EPA's reference dose (RfD) of 0.1 micrograms per kilogram body weight per day as a scientifically justified level to protect human health. There are, however, several research areas identified in the NAS study that need to be addressed. Also, there is a continuing need for ORD to support OW in the development of a revised human health water quality criterion for mercury in FY 2001, and to assist OAR in promulgating regulations to control mercury from coal-fired utilities in FY 2005. Level support in this research area is projected through the FY 2002 - FY 2005 time frame. NCEA is capable of providing technical support and conducting risk assessments, and is leading this effort.

5.3.6 Risk Communication

Research to improve communication to populations at risk of elevated exposures to methylmercury from fish will fluctuate slightly over the FY 2001-2005 period. The Agency needs to develop communication approaches to address risks specific to those who consume large quantities of fish (*e.g.,* persons of Native American and Asian ethnicity) and those who are at heightened risk because of nervous system vulnerability (*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.

5.3.7 Strategic Directions Summary

The six key scientific questions in the *MRS* will meet domestic regulatory commitments and offer international opportunities for addressing mercury. Pressing policy and legislative issues drive ORD's human health and environmental research priorities. While the *Mercury Research Strategy* remains grounded in the risk management paradigm, addressing 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 by stressing the transport, transformation, and fate and combustion risk management research areas. In the longer term, research that advances the understanding of human health effects and exposure, ecological effects and exposure, and non-combustion risk management will be emphasized. Research on communicating the risks of methylmercury exposure to those individuals and groups at greatest risk will be an ongoing effort.

5.4 DETAILED DISCUSSION OF RESEARCH AREAS, KEY SCIENTIFIC QUESTIONS, AND RESEARCH NEEDS

This section of Chapter 5.0 provides a detailed description of the research to be undertaken for each of the six key scientific questions and associated research areas. Each description includes a discussion on background, program relevance, prioritized research needs, research results, and measures of success. The description also contains a list of preliminary performance goals that will be used in mapping out the multi-year implementation plan for the mercury research program. The research needs are identified in order of their relative priority. Each is accompanied by a narrative, the intent of which is to describe the type of work that would be required to address the need.

5.5 TRANSPORT, TRANSFORMATION AND FATE

5.5.1 Key Scientific Question

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 U.S. sources?

5.5.1.1 Background

Mercury bioaccumulates most efficiently in the aquatic food web. Fish-eating birds and mammals 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. The *Mercury Study Report to Congress* supports a plausible link between releases of mercury from industrial and combustion sources in the U.S. and methylmercury in fish. However, fish methylmercury concentrations may also result from existing background concentrations (mercury from natural sources, as well as re-emitted mercury deposited from previous human 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 United States sources. Also, it is unclear how much of the methylmercury in fish consumed by the U.S. population is contributed by emissions from other United States 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.

5.5.1.2 Program Relevance

As methylmercury is the primary route of exposure to both humans and wildlife, it is critical to understand the relationship among methylmercury in fish, levels of ambient mercury in the environment, and emissions from all sources. It is accepted that fish consumption dominates the pathway for human and wildlife exposure to methylmercury. Therefore, a better understanding of this pathway and, to the extent possible, the quantitative relationships among fish intake, methylmercury burdens, residuals in the environment, deposition and emissions, will reduce uncertainties in both risk assessment and risk management. Information on this issue will assist the Agency in prioritizing the management of the diverse sources of mercury in the environment including regulation of combustion sources, pollution prevention activities, remediation of residuals, and international activities. The research being conducted under the Office of Research and Development's (ORD) Science to Achieve Results Program (STAR) will support the first and third prioritized research needs described below.

5.5.1.3 Prioritized Research Needs

- *Improved understanding of the transport, transformation, and fate of mercury in the atmosphere.*
- *Enhanced monitoring of atmospheric mercury deposition for model application.*
- *Improved understanding of the transport, transformation, and fate of mercury in the aquatic and terrestrial media.*
- *Enhanced monitoring of mercury and methylmercury in the aquatic and terrestrial media for improved risk management.*

Research and monitoring needs have been identified in four categories that follow the predominant pathways of exposure from emissions to fish uptake: atmospheric transport, transformation, and fate processes; deposition of mercury from the atmosphere to terrestrial and aquatic environments; fate, transport, and transformation processes in aquatic and terrestrial environments; and monitoring of spatial and temporal patterns of mercury and methylmercury in fish and sensitive environments. 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.

Improved understanding of the transport, transformation, and fate of mercury in the atmosphere. A need exists to provide quantitative estimates of air concentrations and deposition of elemental mercury, reactive gas-phase mercury, and particulate mercury in the U.S. to improve the Agency's understanding of the fate, transport and transformation of mercury. Improvements in atmospheric models will be important in the next few years. Obtaining information on the chemical species and physical form of mercury in emissions, in the atmosphere, and in deposition is vital to accurately modeling 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, human health, and ecological health.

- *Information from an atmospheric modeling framework.* This framework will be based on ORD's new multi-pollutant air modeling system (Models-3), which is being developed and tested for ozone and particulate matter by National Exposure Research Laboratory (NERL) researchers. This new system will replace the highly-parameterized modeling approaches for mercury now in use. The largest process uncertainties are in-cloud chemistry, in-air chemistry and dry deposition of oxidized mercury gas, and these issues will 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. NERL's researchers are currently collecting information in South Florida as part of existing interagency projects involving federal, state, and local agencies. The study includes improved inventories of 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 (50 - 200 kilometers) to predict air concentrations and deposition.* This modeling range is needed for many analyses, such as Total Maximum Daily Load (TMDL) calculations used to link specific sources on a local scale to deposition in specific watersheds and water bodies that may be 10- to 100-200 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 U.S.) do not have sufficiently fine resolution. NERL researchers will examine adding this scale to its current models.

To provide quantitative estimates of air concentrations and deposition of elemental mercury, reactive gas-phase mercury, and particulate mercury in the U.S. that are associated with sources outside the U.S., the following scientific information is needed:

- *Information on the atmospheric fate of mercury species in various scenarios.* 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 atmospheric mercury and its deposition during the Spring months. The Agency needs to understand the mechanisms for atmospheric mercury depletion, whether the mercury is becoming particle-bound and/or transforming to reactive gaseous mercury which affects deposition rates and subsequent bioaccumulation, and whether similar processes occur for ozone depletion. The answer to these questions are critical because partitioning to particulate-and reactive gas-phase could increase the possibility for bio-uptake through the food chain once deposited. This event occurs just prior to the time when Arctic ecosystems are most active. Preliminary research on this topic is being conducted by NERL researchers and researchers from other organizations (e.g., DOE) and is sponsored by OIA.
- *Information on transport mechanisms affecting cross-boundary pollution.* Recent scientific evidence points to a rapid (3-5 day) trans-Pacific transport mechanism tied to meteorological conditions that could bring persistent bioaccumulative toxics (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. This is a topic being pursued by OIA as part of an *International Mercury Strategy*.
- *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.* These measurements, coupled with trace element and back trajectory analyses, permit the modeling of mercury transport to the U.S. 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 the United States 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. Again, this is a topic being pursued by OIA as part of an *International Mercury Strategy*.

EPA must also begin the development of a global scale model for mercury transport, transformation, and fate, including improved emission inventories. Risk management actions to reduce global levels of background mercury are dependent on an understanding of the mechanisms driving mercury flux, which aids in the identification of effective mediation. Without a better understanding of mercury flux from existing mercury pools in the oceans, wetlands, aquatic sediments, Arctic tundra and ice sheets (and wherever else 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.

Research in the Arctic is very important because of unique, natural meteorological conditions there which enhance atmospheric transport of contaminants to the Arctic and then trap them there due to cold conditions. Unique atmospheric transformation processes for mercury are just beginning to be investigated in the Arctic. Researchers are learning that transformation from elemental to reactive gaseous mercury (RGM) is enhanced with increased deposition in Spring. Because mercury and other toxics are trapped there, they tend to be highly bioconcentrated in organisms which have short food chains to top predators, including humans. The most vulnerable populations to mercury exposure are those reliant on indigenous foods tied to fish consumption, and Alaska has native tribes and villages which depend heavily on subsistence foods, including polar bear and marine mammals, and fish-eating birds and their eggs. Research is needed in the Arctic, to understand unique processes, and ecological and human health linkages.

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. Because the *Mercury Research Strategy* is focused primarily on resolving domestic issues related to mercury and methylmercury risk assessment and risk management, these topics must be addressed in the larger context of the international implications of mercury.

Enhanced monitoring of atmospheric mercury deposition for model application. There is a need to improve the monitoring of atmospheric mercury deposition. NERL 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 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 has proposed 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. Platforms can provide valuable information on mercury deposition resulting from international sources, and will contribute to agreements such as the United States-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.

Improved understanding of the transport, transformation, and fate of mercury in the aquatic and terrestrial media. There is a 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 understanding 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. In particular, the role of sulfur and selenium in controlling the toxicity and/or bioavailability of methylmercury is poorly understood. Terrestrial and aquatic models incorporating current process understanding at different scales will be developed and validated. These models must be fully consistent and integrated with the atmospheric models discussed above. Fundamental research is being conducted as part of the NCER's STAR Grants Program (Refer to Appendix A).

In cooperation with other federal, state, and local agencies and industrial groups, 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. The long-term goal is to 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. The 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, the South Florida Water Management District, and the Electric

Power Research Institute. Lessons learned in this ongoing project will be applied nationwide.

Critical questions for wildlife exposure and biological transport to humans include: (1) to what extent does transboundary transport of mercury occur via migratory species when boundaries are shared between the U.S. and other countries (including shared water bodies), (2) and how significant is this fish and wildlife migration for vulnerable U.S. wildlife and human populations due to uptake through the food chain? EPA knows that older fish of some species have elevated levels of mercury, and this is also true of beluga whales and sea otters. Likewise, 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 chain is needed and will be addressed as part of the *International Mercury Strategy*.

EPA believes that this is an important research area, in that more information is becoming available showing that migratory species with body burdens of toxics (which could be enhanced by their spending time in more highly polluted areas in other countries, such as Russian waters, or areas near industrial Asian sources) can release the bioaccumulated contaminant to the environment to which they migrate, and enhance bio-uptake there. It is known that the large predatory fish, tuna, is one of the most wide-ranging animals, can cross the Atlantic in fewer than 50 days, and lives to be 40 years old. Migratory salmon and whales can spend time in Russian waters and then migrate back to Alaska, and migratory birds do the same. These are all eaten directly by indigenous peoples in Alaska , and bird eggs are also consumed. They constitute a large part of the indigenous diet. Recent studies of PCBs in bird eggs in Alaska showed elevated levels. Fish in the Bering Sea are a tremendous resource for consumers there and also in the lower 48 States. It is important to know if Arctic species are being more contaminated via direct migration to areas where uptake can be enhanced, or indirectly through food linkages to such more highly-exposed animals. It is premature to say that transboundary linkages are insignificant from a food chain perspective.

Enhanced monitoring of mercury and methylmercury in the aquatic and terrestrial media for improved risk management. The Clean Water Action Plan (EPA, 1998a) calls for a survey of a wide range of pollutants in fish tissue (including mercury). There are two basic goals: (1) provide a statistically representative distribution of those chemicals known to accumulate in fish flesh and (2) determine whether there are other chemicals of concern. Designed by ORD's Environmental Monitoring Assessment Program (EMAP) Program and administered by OW, this survey is statistically based so that it is repeatable and able to detect trends in mercury and to measure progress toward attaining Government Performance and Results Act (GPRA) goals. 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 which links existing and planned deposition monitoring sites with sentinel environments where mercury methylation is most likely to occur (*e.g.,* wetlands).

5.5.1.4 Research Results

Results from this research will provide an improved understanding of the fate and transport of mercury and methylmercury in all environmental media and will allow the Agency to identify those mechanisms that are most active in mercury transformation processes. Linked to an improved understanding of mercury releases from sources and sinks, this research will also allow the Agency to better estimate U.S. contributions to mercury in air and water, and on land. Research on transport, transformation and fate will also indicate how reductions in mercury through both regulatory and voluntary actions result in concomitant reductions in methylmercury in both humans and wildlife. This work will be particularly useful for risk managers when considering technological approaches to managing methylmercury in aquatic and terrestrial settings.

5.5.1.5 Measures of Success

Researchers hope to advance the following:

- Measurable improvement in the scientific understanding of the linkage among methylmercury in fish, ambient mercury in the environment, and emissions.
- Identification and control of other pollutants that exacerbate or minimize the mercury problem (*e.g.,* acid, sulfur, selenium, nutrients).
- 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; of evaluating the relative importance of local, regional, and global sources of mercury; and of determining the importance of natural sources, re-emitted mercury formerly deposited from anthropogenic and geological sources, and new emissions.

5.5.1.6 Preliminary Performance Goals

- By 2003, develop a continuous ambient monitor capable of distinguishing atmospheric mercury species.

- By 2006, provide an improved model for mercury in terrestrial and aquatic systems capable of tracking the fate of mercury from sources to concentrations in fish tissue.
- By 2008, produce an improved atmospheric fate and transport model for mercury capable of distinguishing among sources of mercury deposition; along with an assessment of atmospheric mercury transport and fate, including an enhanced scientific understanding of, and then an improved inventory for, the chemical and physical forms of mercury emissions.

5.6 RISK MANAGEMENT FOR COMBUSTION SOURCES

5.6.1 Key Scientific Question

How much can mercury emissions from coal-fired utility boilers and other combustion systems be reduced with innovative mercury and multi-pollutant control technologies; what is the relative performance and cost of these new approaches compared to currently available technologies?

5.6.1.1 Background

Combustion systems that burn fossil fuels such as coal or waste materials containing mercury are major sources of mercury emissions to the air. Mercury emissions from these anthropogenic sources eventually get 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 report released in 1998 by the Northeast States for Coordinated Air Use Management (NESCAUM) contains results from regional modeling studies supported by EPA (Regional Lagrangian Model of Air Pollution [RELMAP]) that indicate 77 percent of mercury emissions (anthropogenic and natural) deposited in the Northeast are from sources within the United States; and only 23 percent 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 mercury emissions from combustion facilities and other anthropogenic sources. While increased use of natural gas for power generation and implementation of recent Clean Air Act (CAA) regulations for several types of waste combustion systems will result in some reductions of combustion-generated mercury, combustion facilities remain a significant source in the United States (accounting for 87 percent of the total point source emissions) with coal-fired utility boilers being the largest single source type (EPA, 1997a).

5.6.1.2 Program Relevance

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. Current concerns about the lack of adequately demonstrated, cost-effective mercury emission control technologies applicable to coal-fired boilers and associated equipment pose constraints to development of mercury emission reduction requirements for these sources. As a result, OAR has identified research needs on emission reduction options for utility boilers as its highest mercury research priority. To address OAR's needs, mercury combustion control research will focus on determining the cost and effectiveness of viable options to reduce mercury releases from coal-fired boilers. 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 research results will also be useful to international organizations and countries concerned with mercury emissions from combustion sources. 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.

Reducing mercury emissions from combustion sources is complex because there are a wide variety of fuels and waste streams and many different types of combustion configurations, flue gas cleaning methods, and operating modes. Conventional options such as fuel switching, fuel pretreatment (i.e. coal cleaning), waste feed limitations and activated carbon injection are available to reduce emissions; however, there are many instances where these approaches do not achieve adequate emission reductions, are not practical, or have been inconsistent or ineffective in the field. The effectiveness of different control methods is influenced by variables such as the properties of the fuel or waste, the source operating conditions, flue gas cleaning technologies employed, and the species of mercury in the flue gas. In combustion systems, mercury is volatilized and converted to elemental mercury vapor (Hg^0) in the high-temperature regions of furnaces. As the flue gas is cooled, mercury is converted to gas-phase ionic (Hg^{+2}) and particulate-bound (Hg_p) forms of mercury.

"Speciation" is a term used to denote the relative amounts of Hg^0, Hg^{+2}, and Hg_p in flue gas. The rate of conversion of gaseous Hg^0 to Hg^{+2} and Hg_p is dependent on the temperature, flue gas composition, and the amount and properties of entrained particles (fly ash and sorbents). Mercury speciation is a particularly important variable for flue gas cleaning because it directly impacts the capture of the mercury. For example, mercuric chloride ($HgCl_2$) 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 $HgCl_2$. However, elemental mercury 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. In incinerators, the flue-gas concentration of chlorine is substantially higher than that of Hg^0, and results in preferential conversion of Hg^0 to $HgCl_2$. In coal-fired combustion units, where concentrations of chlorine are much lower and SO_2 is present, mercury may remain predominantly in the elemental form.

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. Current data from EPA's Information Collection Request (ICR) for coal-fired utility boilers and recent field tests indicate that significant mercury capture is being achieved at coal-fired electric utility boilers through inherent fly ash sorption and collection in existing particulate matter (PM) collectors. These data also indicate that even more substantial capture occurs for systems using sulfur dioxide (SO_2) scrubbers and post-combustion nitrogen oxide (NO_x) controls. Significant additional control of mercury emissions will require either addition of dry sorbents upstream of the existing PM controls or will be achieved through implementation of advanced controls and strategies for compliance with fine PM, ozone non-attainment, regional haze and New Source Review requirements, as well as efforts undertaken to reduce Toxic Release Inventory (TRI) pollutants such as hydrochloric acid (HCl) and sulfur trioxide (SO_3). Future development of optimal mercury and multi-pollutant combustion source controls will therefore require an improved understanding of the fundamental processes that influence the species of mercury emitted, and testing and evaluation of innovative approaches to capture mercury in an environmentally and economically acceptable manner. In this regard, several of the *critical uncertainties* are:

1. how mercury speciation and capture in combustion systems is influenced by fuel or waste properties, combustion conditions, and flue gas cleaning methods;
2. the extent to which modifications in combustion and flue gas cleaning conditions can cost-effectively reduce emissions of various mercury species and co-pollutants;
3. how to measure combustion source emissions of mercury on a continuous basis; and
4. whether mercury contaminated residuals from air pollution control systems will need to be stabilized before disposal.

Over the next three to five years, ORD will work with the Department of Energy (DOE), the United States Geological Survey (USGS), and private sector organizations to address the key scientific uncertainties described above. Studies will be conducted to identify, evaluate, and demonstrate innovative technological solutions that can cost-effectively reduce mercury emissions from currently unregulated sources or those for which improved technologies would significantly reduce the costs to comply with existing regulations. The relative costs of controlling mercury only and of controlling mercury in conjunction with other pollutants such as fine (PM) and fine PM precursors (sulfur dioxide and nitrogen oxides) will also be quantified.

The four research areas identified below were chosen based on priorities identified by OAR, OSW, and external stakeholders; scientific uncertainties (data gaps) that currently impede implementation of mercury controls for specific sources; and the potential to reduce control costs. Research in these areas is critical to support future regulatory impact analyses, particularly those that include mercury in a multi-pollutant framework, and to ensure that viable options are available for all types of boiler configurations and associated operating conditions. In addition, without adequate data on *combustion chemistry and associated operating conditions,* it will be difficult to develop better technologies and to understand why existing technologies do not perform consistently in the field.

5.6.1.3 Prioritized Research Needs

- *Improved understanding of managing mercury species in combustion processes.*
- *Improved understanding of performance and cost of mercury emissions controls.*
- *Increased testing and evaluation of mercury continuous emission monitors.*
- *Improved characterization of, and management approaches for, mercury controls residuals.*

Improved understanding of managing mercury species in combustion processes. A need exists to determine the parameters, including chemical and physical mechanisms and combustion operating conditions, that affect mercury species emitted from combustion systems, and to identify potential approaches to capture these species. The capture of mercury in a pollution control device is dependent on mercury speciation *(i.e.,* the chemical forms of mercury). A fundamental understanding of the chemical and physical mechanisms and combustion conditions that influence the speciation of mercury in a combustion system is essential to determine the approaches that will provide effective capture. Specific research planned will: (1) determine how fuel or waste properties, combustion conditions (temperatures, residence times, and quench rates), flue gas composition, fly ash, and sorbent properties, and flue gas cleaning equipment affect mercury speciation; (2) evaluate whether mercury speciation can be controlled by using reagents, catalysts, or adjustments to the combustion process conditions; (3) identify fly ash, sorbent, and flue gas properties that lead to high levels of mercury adsorption and determine whether changing combustion conditions will enhance adsorption; (4) determine the solubility of different mercury species as a function of different scrubber operating conditions (temperature, dissolved species, and reagents); and (5) determine the scrubber conditions necessary to convert Hg^0 to the easier-to-capture species. NRMRL 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.

Improved understanding of performance and cost of mercury emissions controls. A need exists to 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 research conducted to characterize mercury speciation and control mechanisms and develop sorbents, field tests will be conducted to evaluate the effectiveness of different equipment configurations, reagents, sorbents, and process conditions for controlling mercury emissions. Studies to determine the potential mercury emissions reductions that can be achieved by technologies currently used to reduce criteria air pollutants will also be conducted. Preliminary evaluation of ICR data indicates that technologies currently in place for control of criteria pollutants achieve reductions in mercury emissions that range from less than 10 percent to more than 90 percent. The level of co-control currently achieved can be increased by application of mercury retrofit technologies. Improved mercury control can also be achieved by methods designed to increase capture of more than one pollutant. This approach can utilize the synergisms that accrue through the application of multi-pollutant control technologies. The co-benefits can be maximized by linking mercury control to the reduction of the other regulated pollutants such as NO_x, and SO_2.

Current estimates of mercury control costs using powdered activated carbon (PAC) injection range from 0.31 to 3.78 mills/kwh depending on the type of coal used and the control technologies already in place. Engineering cost studies will be conducted to provide updated estimates of capital and operating expenses for PAC and innovative mercury retrofit control technologies. These updated costs will take into account the latest information available on the type of coal used and air pollution control systems in place. As part of this effort, research is planned to develop the methodology and data required to quantify the incremental mercury control costs for various multi–pollutant control options. NRMRL and DOE are coordinating with utility companies and technology vendors to test promising mercury and multi-pollutant control technology options in the field. The DOE has already solicited proposals. Their main role will be to select the test sites based on proposals submitted and provide funds for testing; industry will co-fund by providing the equipment and power plant upgrades, and NRMRL will play a lead role in collecting information on mercury emission levels both before and after the control device. More information on the activities of DOE and EPRI are discussed in Chapter 4.0. Finally, ORD will work with OAR to evaluate other mercury control options feasible for the electric utility industry, such as changes in dispatch patterns and fuel mix.

Increased testing and evaluation of mercury continuous emission monitors. A need exists to evaluate the performance and application of continuous emissions monitors (CEMs) to measure total mercury and the species of mercury present in combustion emissions even at very low concentrations. The ability to evaluate the performance of control technologies, determine compliance with regulations, and better characterize source emissions to support risk assessments requires CEMs that are capable of accurately and reliably quantifying both total mercury (Hg) as well as the speciated forms of Hg emitted from combustion sources, particularly at trace levels. Currently, total mercury CEMs are commercially available and widely used in Europe and their performance accepted. However, acceptable performance in the U.S. cannot be assumed, as pollution control device configurations in the U.S. vary greatly from those found in Europe. These CEMs are still susceptible to measurement interferences from combustion gases such as SO_2, hydrogen fluoride, HCl, and NO_x. In addition, most units are not capable of measuring the particulate-bound mercury component. As a result, PM is routinely filtered out, and remains unmeasured.

While there are no commercially available units that directly measure the various mercury species, significant strides have been made over the last few years. Many total gaseous mercury CEMs can be used to indirectly measure mercury species (the elemental and oxidized forms) by determining the difference between the elemental mercury and total gaseous mercury. This difference is recognized as the oxidized form. Separate mercury measurements are made before and after the conversion step in order to calculate the oxidized form ("speciation by difference"). Several vendors are currently attempting to develop a mercury CEM that is capable of differentiating the species of mercury. Research is needed to identify the appropriate methods of measuring total mercury and the mercury species (the chemical forms of Hg) in combustion system flue gases. ORD's Environmental Technology Verification Program is planning to verify CEM performance against vendors' claims.

Research is needed to: (1) investigate the biases associated with total and speciated mercury measurements, particularly those associated with particle-bound mercury and the effects of interferences; DOE is sponsoring research to investigate sample conditioning techniques that address bias associated with speciated mercury measurements (by difference) and reactive particulate matter; and (2) evaluate the performance of total and speciated CEMs through both pilot-scale and field testing. Research also needs to be performed to determine if one method will work for all combustion sources or whether different methods must be used, and evaluate whether continuous measurements of mercury can confirm the effectiveness of feed limitations and thereby reduce compliance costs (*i.e.,* prove that emissions levels have been met without costly sampling of input stream). NRMRL is working with DOE in this area and will support field evaluation of the techniques identified under item 1 above.

Improved characterization of, and management approaches for, mercury controls residuals. There is a need to 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. Use of sorbent injection technologies to control emissions at electric power plants typically results in residues, which are either used as byproducts or are disposed. The total generation of coal combustion residues in 1998 was ~108 million tons, with ~77 million tons landfilled and ~31 million tons utilized. OSWER has indicated that composition data characterizing the different residues, as well as data on the composition of leachate are needed for total and speciated mercury, arsenic, and other toxics in these residues. These data are needed for calculating the mass balance flows associated with the management of mercury-contaminated residuals from coal-fired power plants.

No information is currently available on the potential life-cycle environmental burdens resulting from volatilization of mercury from byproducts and disposed residues. In order to ensure the mercury is not simply released into soil or groundwater, or subsequently released in air, research is needed to: (1) characterize any releases associated with the residues, and (2) develop ways to correctly manage the residues, including stabilizing the mercury before it is sent for land disposal, to prevent any subsequent release of mercury back into the environment. Research will focus on those waste management practices that are suspected of having the greatest potential for release of mercury including utilization of mercury containing residues in cement and wallboard production and production, and application of asphalt. The results from this research will provide a better set of data characterizing the various residue types and an improved understanding of the ultimate fate of mercury in the various practices in use to manage residuals from coal-fired power plants.

NRMRL will take the lead to synthesize results from the research described above including data generated by other federal agencies, academia and industry *(ORD does not plan to conduct research to evaluate improved techniques to clean coals prior to combustion; however, results of any research conducted by other federal agencies or private industry will be included in the integrated outputs*). Concise summaries of technology costs and performance will be provided to OAR and other interested stakeholders to assist them in evaluations of alternative mercury emission reduction options. These integrated research summaries will include information on how to control the various forms of mercury emitted and how integrated combinations of technologies can be used to simultaneously control mercury and other air pollutants of concern.

5.6.1.4 Research Results

Results from this research will provide improved data on the cost and performance of control technologies and other risk management options capable of reducing mercury emissions from priority combustion source categories (*e.g.* coal-fired utilities). OAR, OW, OSWER, and other Program Offices will use the data and information from this research to support regulation development for combustion sources where the Agency has a statutory responsibility to address mercury emissions. This work will also help states, Regions, and the private sector determine how specific technologies or approaches can be used to meet emissions standards or voluntary reduction targets that have been negotiated with EPA.

5.6.1.5 Measures of Success

Researchers hope to advance the following:

- Identification of the combustion conditions that have the most significant impact on the species of mercury formed in coal-fired utility boilers.
- Development of innovative mercury and multi-pollutant control systems that remove 70 to 90 percent of mercury at the lowest possible costs.
- Identification of viable approaches to measure both total mercury and species of mercury.

- Full characterization of the releases or emissions of mercury from waste management and utilization practices.
- Completion of successful demonstrations, at full or large pilot-scale, of innovative options to reduce mercury emissions from coal-fired utility boilers.
- Development of the most up to date information on the costs of mercury and multi-pollutant control options to support regulatory decisions.
- Production of a handbook on mercury controls to support implementation of regulatory requirements. This handbook will summarize information on the relative performance and cost of reducing mercury emissions using pretreatment approaches, flue gas cleaning technologies or combinations of these approaches with other air pollution control systems (co-control).

5.6.1.6 Preliminary Performance Goals

- By 2003, produce a comprehensive summary report (capstone report) documenting the performance of devices used to continuously measure total or species of mercury.
- By 2004, produce a technical assessment of the life-cycle implications of mercury-contaminated residues from air pollution control systems including the cost and performance of any required stabilization technologies.
- By 2005, complete comprehensive assessment of the capability of mercury control technologies and other risk management options (*e.g.* fuel switching) to achieve reductions from 70 to 90 percent in the most cost-effective manner (lowest $ cost per unit of pollutant removed).

5.7 RISK MANAGEMENT FOR NON-COMBUSTION SOURCES

5.7.1 Key Scientific Question

What is the magnitude of contributions of mercury releases from non-combustion sources; how can the most significant releases be minimized?

5.7.1.1 Background

While available data on the use and release of mercury in the non-combustion source category are limited, some available data indicate the total disposition of mercury by various segments of this category in the United States. In 1995, this category consumed 436 tons of mercury and contributed about 13 percent (20 tons) to U.S. mercury emissions. In the same year, over 12.2 million metric tons of mercury-bearing hazardous wastes were generated (EPA, 1998f), and an estimated 227 tons of mercury were disposed of in municipal landfills as part of mercury-bearing solid wastes. (EPA, 1997a)[1]

Because of the wide variety of sources and difficulties in measuring mercury emissions, estimates for some U.S. sources are believed to be low. However, these sources generally have low stacks or vents (and in some cases release soluble mercury compounds, such as $HgCl_2$ or even methylated mercury compounds) that may result in higher rates of local exposures per unit emissions compared to combustion sources. The numerous anthropogenic activities that use mercury produce mercury-bearing wastes and consumer products (including bulk elemental mercury) will pose a long-term threat to the environment if not disposed of properly. On a national scale, the magnitude of releases of mercury to soils and water by non-combustion sources appears relatively small. However, current and past releases are the sources for local “hot spots” of mercury contamination, and any significant releases from these hot spots need to be minimized.

5.7.1.2 Program Relevance

As reflected in the *Draft EPA Action Plan for Mercury* (Federal Register, 1998), the Agency proposes to reduce mercury releases from non-combustion sources using a number of approaches, including regulations (*e.g.,* Maximum Achievable Control Technology for chlor-alkali plant emissions) and promotion of voluntary activities by industry to reduce mercury use (*e.g.,* mercury takeback programs). Site- and facility-specific problems are being addressed by EPA Regional Offices. In some cases, improved characterization of mercury sources is needed prior to selecting options for reducing releases. The results of improved approaches to characterizing and 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 important Agency activities.

5.7.1.3 Prioritized Research Needs

This section describes major remaining 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. The scope of this section covers three phases of non-combustion risk management research:

- *Characterization of the mercury life cycle in human activities (Phase I).*
- *Improved understanding of mercury releases from sources and sinks (Phase II).*

- *Approaches for minimizing mercury releases from non-combustion sources (Phase III).*

While the scope of research activities in this section is broad, in keeping with the general approach of this strategy the research in this section will address only the most significant information gaps. Factors to be used in determining relative significance include the magnitude and uncertainty associated with characterizing and controlling releases to determine their risk, as well as the cost and effectiveness of characterization and control techniques. Also, a phased approach of progressively focused, in-depth studies will be used to maximize the impacts of the research program. In some cases, work will have to progress through all three phases. In other situations, the significance of an issue is well enough understood to proceed immediately to later phases. For example, ORD started investigating improved treatment options for hazardous waste disposal in FY 1999.

Because of the high EPA priority on management of mercury releases from combustion sources, studies of non-combustion sources will be limited through at least FY 2002. Therefore, some of the research needs described in this section may not be addressed until FY 2005 or beyond. ORD has organized its non-combustion risk management research program into project areas based on source type. Research in FY 2001 and FY 2002 will focus principally on source emissions characterization, process waste and mercury stockpile disposal, and options for reducing mercury use. During this period, characterizations of the mercury life cycle in human activities and its associated mercury releases should help to further focus research in these areas in FY 2003 through FY 2005. The significance of mercury from contaminated media such as sediments and mining residuals should also be better understood by FY 2002, allowing ORD to plan research activities in these areas for FY 2003 through FY 2005.

Characterization of the mercury life cycle in human activities (Phase I). There is a need to conduct a preliminary characterization of the mercury life cycle. The purpose of this activity is to understand the current flow of mercury in the United States from production to disposal, and to identify the significant release points during its life time. The results of this work will focus further ORD's releases characterization and control research. It should also identify human activities that have resulted in areas of major soils or sediments contamination.

Two activities are currently planned in this area:

- Evaluation of mercury use in the industrial sector to determine opportunities for reducing environmental impacts through source reduction;
- A preliminary inventory to re-evaluate releases data and identify the non-combustion sources with the most significant releases. The resulting "significant" sources will be characterized in more detail (see Phase II).

The evaluation of mercury use will update existing models of mercury flow in United States commerce. Besides helping to identify source reduction opportunities, it will also provide the Agency with basic information to create a supply and demand model for mercury in the United States. Such a model could be used to determine how economic and regulatory conditions might alter the flow of mercury in the United States. Such futuristic scenarios would also be an important additional contributor to focusing ORD's mercury research program. Because of the current emphasis placed on air emissions sources by the Agency, ORD initial releases inventory work will start in this area. ORD will work with the Office of Air and Radiation (OAR) to update available screening inventories of source emissions, such as that produced in *The Mercury Study Report to Congress*. By FY 2002, ORD plans to have conducted sufficient preliminary evaluations of mercury emissions to refine research priorities for Phases II and III.

Improved understanding of mercury releases from sources and sinks (Phase II). A need exists to better characterize mercury releases to the environment. While mercury releases are well characterized from some sources, that is not the case for all. For example, there is uncertainty about the magnitude of both elemental and speciated mercury air emissions from some sources that were identified in *The Mercury Report to Congress* as having releases below 10 tons/year. In many cases these uncertainties arise because good sampling or analytical techniques do not exist. In other cases, sufficient releases data have not been collected. ORD mercury releases characterization studies are intended to develop better sampling or analytical techniques on a source-specific basis, and to sample a very limited number of sources to better characterize their emissions. This releases characterization research will be carried out on a particular source type if sufficient data already exist to show it to be a potentially significant source, or if the results of Phase I so indicate.

NRMRL is currently targeting emissions characterization studies from: (1) mercury-cell chlor alkali plants (MCCAPs) and (2) municipal landfills. MCCAPs were identified because of the large discrepancy between their annual mercury makeup (about 160 tons/year) and their estimated 7.1 tons/year in mercury releases (EPA, 1997a). Mercury emissions from municipal landfills will be studied as part of an Agency program addressing PBT emissions from municipal landfills. While existing data suggest that landfills may not be a major source of inorganic mercury, the data also suggest that methylated mercury compounds may be emitted. Other sources of mercury air emissions that may require characterization include the oil and petroleum industry. The significance of their emissions will be considered along with others from non-combustion sources in the preliminary emissions inventory work of Phase I to determine if emissions characterization research is needed for them in Phase II.

Mercury releases can also occur in the form of solid waste and water effluent streams. Mining effluents are believed to be the most significant mercury effluent source, causing regional contamination problems. Mercury-bearing effluents from mining appear to cause significant sediments contamination and associated fish advisories in receiving rivers and lakes, particularly in the western United States. Preliminary studies will be conducted to better characterize mercury releases from mines in order to determine whether the problem is significant enough to warrant control research. ORD will continue to work with the Mercury Task Force (MTF) to determine other significant mercury effluent sources.

Waste streams pose more uncertainties. It is difficult to characterize mercury-bearing wastes, and how they release mercury under the range of environmental conditions found in disposal facilities. Because of this, and as part of its support of the EPA Office of Solid Waste (OSW) rulemaking to revise the Land Disposal Restrictions (LDRs) treatment standards for mercury-bearing wastes, especially "high subcategory" mercury wastes (*i.e.,* wastes containing over 260 ppm total mercury), ORD is evaluating improved characterization techniques for mercury in wastes. Both sediments and soils can be sources of mercury releases to air or surface waters. (Ground water is not viewed as a significant exposure pathway). Sediments are a significant sink for air- and water-borne mercury releases. Sediments are also host to the base of the food web that extends through aquatic organisms to land-based wildlife and humans. There are also a number of sites with significant contaminated mercury in soil, and while elemental mercury in soil is not highly soluble, it may be volatilized, or methylated and enter the food chain.

Approaches for minimizing mercury releases from non-combustion sources (Phase III). There is a need to identify alternate approaches for minimizing mercury releases. Mercury releases can be minimized by reducing the use of mercury or by use of end-of-pipe controls, including waste treatment. NRMRL will study both approaches, focusing on major release sources. Source reduction opportunities will be identified in the mercury-use study in Phase I. Selections will be based on release potential, industry interest in voluntary reduction, and other factors. For these selected sectors, ORD will conduct research to advance the reduction of mercury use. This research, done in collaboration with industry where possible, will include application of life cycle analysis (LCA) tools and studies of innovative source reduction processes.

Sources requiring mercury control research will be identified based on the magnitude of the release, availability of cost-effective control techniques, and Agency priorities. For example, if releases of mercury are significant from MCCAPs or mining, then control research may be required because cost-effective means of controlling non-point source releases is often difficult. Treatment technology research on hazardous wastes bearing high concentrations (>260 ppm) of mercury is an OSW priority because they are currently investigating alternatives to incineration and retorting. The research needs, collaboratively identified with OSW, include improved waste characterization and alternative technology research and demonstration.

The ultimate disposal of mercury stockpiles is also of concern. Large stockpiles already await disposal. For example, The Department of Defense (DOD) currently manages a mercury stockpile of approximately 4,400 metric tons. The total amount of stockpiled mercury in the United States will be increasing as the number of federal, state and local programs to reduce mercury use and to recycle mercury products increase. Environmentally safe disposal alternatives for elemental mercury have not been fully evaluated in terms of long-term effectiveness and cost. ORD will work with the EPA Mercury Task Force and outside stakeholders to determine major research needs and to address those where expertise is available.

Three approaches are available for the management of mercury in sediments: capping, in-situ methods, and dredging followed by confinement or treatment. Natural processes affecting Hg in this environment must also be understood. NRMRL has an established contaminated sediments research program and many of its research findings for metals are applicable to mercury. However, research is needed on in-place management of mercury-contaminated sediments that focuses understanding and enhancement of 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. Particular emphasis will be given to disrupting the formation of methyl-mercury.

Research on remediation options for soils contaminated with mercury is a lower relative priority, although remediation of these sources must ultimately be addressed. Contaminated soils remediation may be of high priority on a site-specific basis. Remediation options for such sites are under development by others, such as 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.

5.7.1.4 Research Results

Results from this research will contribute to an improved understanding of mercury releases from non-combustion sources, and where appropriate, sinks (*e.g.,* contaminated sediments, abandoned gold mining sites). While emissions from coal-fired utilities and other combustion sources are fairly well understood, this is not the case for other sources of mercury. The Program Offices, Regions, and states will all benefit in terms of regulatory and voluntary actions for mercury with a better understanding of the releases from a variety of sources. Work will also be targeted at approaches that minimize mercury releases into the environment, including the ultimate disposition or retirement of excess metallic mercury stocks.

5.7.1.5 Measures of Success

As indicated above, research on the non-combustion risk management research area starts at a modest level, likely expanding in FY 2004 as the need for combustion risk management research declines. The ability of ORD to accomplish all the research described in this section is resource dependent and will likely need to continue past FY 2005 in order to reach the measures of success described below. In addition, Phase I research during the early years of the program may identify higher priority research needs, and therefore some research activities described here could be dropped altogether. Consequently, the measures of success described below are those currently identified for priority research needs, but these measures are subject to change as our understanding of non-combustion mercury releases grows.

1. Characterization of the mercury life cycle in human activities (Phase I)

- Assessment of anthropogenic mercury use to identify major opportunities for reducing use and/or releases.
- Assessment of the relative significance of mercury emissions from anthropogenic sources in the United States.

2. Improved understanding of mercury releases from sources and sinks (Phase II)

- Identification and/or evaluation of technologies and techniques that provide improved MCCAP facility emissions measurements.
- Improved characterization of air emissions from priority source categories, such as MCCAP, landfills and oil and gas processing facilities.
- Identification of mining waste types that contribute most to mobile mercury.

3. Approaches for minimizing mercury releases from non-combustion sources (Phase III).

- Improved understanding of the effectiveness and cost of vendors' innovative technologies for control of air emissions from high priority source categories.
- 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 hazardous waste treatment residuals.
- Evaluation of several pollution prevention approaches for reduction of mercury use, and determination of the reduction in adverse environmental impacts.
- Improved understanding of the processes that control mercury transport and re-transformation in sediments.
- Development and/or evaluation of three technologies to control mercury transport or bioavailability at abandoned mining sites.
- Assessment of the options for ultimate disposal of mercury stockpiles.

5.7.1.6 Preliminary Performance Goals

Current GPRA Annual Performance Goals (APG) for this program reflect the phases of activities of the program (FY 2003 and FY 2006 APGs) and the anticipation that the program should take about 10 years to complete. The APGs are:

- By 2003, provide technical resource documents to public and private decision makers and other stakeholders on the magnitude of releases of mercury from non-combustion sources and recommend methods for characterizing emissions for priority sources.
- By 2006, provide technical resource documents to public and private decision makers and other stakeholders on options for cost-effectively reducing releases from priority non-combustion sources including "low tech" approaches for reducing mercury emissions.
- By 2007, provide technological transfer of control and mercury reduction technologies for combustion and non-combustion sources.
- By 2009, provide an authoritative set of risk management options to public and private decision-makers and other stakeholders for priority non-combustion sources of mercury releases to the environment.

5.8 ECOLOGICAL EFFECTS AND EXPOSURE

5.8.1 Key Scientific Question

What are the risks associated with methylmercury exposure to wildlife species and other significant ecological receptors?

5.8.1.1 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 fish-eating 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* (EPA, 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 fish-eating wildlife and to calculate water-based wildlife criteria for mercury that are protective of fish-eating wildlife populations. The Agency recognizes that this prioritization could change substantially as new information about mercury exposure and effects becomes available. In many cases it is difficult, and sometimes counterproductive, to consider chemical effects apart from exposure. The emphasis of this effort is on research needs for ecological effects assessments and ecological risk assessment. Section 5.5 focuses on the fate and transport of mercury. Section 5.5.1.3 includes research on aquatic and terrestrial transport, transformation, and fate, and will supply exposure data concerning ecological endpoints. Results from the effects and exposure research, along with distributional assessment methods, will produce a state-of-the-art ecological risk assessment for mercury.

5.8.1.2 Program Relevance

Mercury pollution of aquatic systems is a national problem. At the end of 1998, fish consumption advisories due to unacceptable levels of mercury existed in 40 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 area will serve to strengthen the scientific credibility of water quality criteria for mercury and procedures for implementing those criteria in watersheds throughout the Nation.

5.8.1.3 Prioritized Research Needs

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

- *Improved understanding of methylmercury toxicity effects on avian and mammalian wildlife.*
- *Refined ecological assessments for avian and mammalian wildlife risks.*
- *Improved understanding of ecological impacts of methylmercury on avian and mammalian wildlife.*
- *Improved understanding of ecological impacts of methylmercury on non-avian and non-mammalian species.*
- *Identification of interactions among methylmercury and other chemical and non-chemical stressors on all ecological receptors.*

Improved understanding of methylmercury toxicity effects on 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 reference dose (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 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 highly exposed species.

Refined ecological assessments for avian and mammalian wildlife risks. The research above will contribute to improve 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 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 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.

Improved understanding of ecological impacts of methylmercury on avian and mammalian wildlife. Using a "weight of evidence" approach, the authors of the *Mercury Study 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-recover 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.

Improved understanding of ecological impacts of methylmercury on non-avian and non-mammalian species. Based largely upon exposure considerations, it may be concluded that piscivorous avian and mammalian wildlife species are most at risk from 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 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 or food web relationships, experience mercury exposure comparable to that of piscivorus wildlife.

Identification of interactions among methylmercury with other chemical and non-chemical stressors on all ecological receptors. 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 (EPA, 1997a). 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.

5.8.1.4 Research Results

Results from this research will be used by NCEA in refined mercury ecological risk assessments that will support future policy decisions on safe mercury levels for fish, birds, and other animals. Data that are developed will contribute to an improved sensitivity analysis and assist in reducing uncertainty in a number of areas pertinent to mercury effects and exposures in ecosystems. Using these refined risk assessments will help OW provide more informed guidance on methylmercury in water bodies. This work will also assist States in making decisions on action levels for mercury total maximum daily loads (TMDLs).

5.8.1.5 Measures of Success

Researchers hope to advance 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.

5.8.1.6 Preliminary Performance Goals

GPRA performance goals have been identified for the ecological effects and exposure research area based on the above Measures of Success. They are preliminary in nature and will be revised and adjusted as part of the implementation of the *Mercury Research Strategy*. A preliminary set of performance goals is offered below. The performance goals are:

- By FY 2003, prepare a report characterizing the toxicokinetics and toxicodynamics of methylmercury in avian species.
- By FY 2005, prepare a report on regional variability factors leading to a probabilistic ecological risk assessment on methyl mercury.
- By FY 2007, conduct a regionally based probabilistic ecological risk assessment of the effects of methyl mercury on representative avian and wildlife species.

5.9 HUMAN HEALTH EFFECTS AND EXPOSURE

5.9.1 Key Scientific Question

> *What critical changes in human health are associated with exposure to environmental sources of methylmercury in the most susceptible human population? How much methylmercury are humans exposed to, particularly 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?*

5.9.1.1 Background

Health Hazards

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 methylmercury's adverse effects on children's neurological development. Other federal agencies (e.g., FDA) continue to base their regulatory activities on effects in adults or have developed assessments (e.g., ATSDR's Toxicology Profile on Mercury [ATSDR, 1999]) aimed at a fetal protective dose based on epidemiological studies of other populations. Between 1995 and 2000, deliberations have focused on the appropriateness of specific epidemiological investigations for risk assessment. Following an FY 1999 Congressional budget appropriation for the National Academy of Sciences (NAS) to conduct a study on toxicological effects of methylmercury, a report was released from the NAS in July 2000 (NRC, 2000). This effort involved a review of the health research on mercury conducted since the completion of the Mercury Study Report to Congress released in 1997. The NAS Committee's report recommended the following:

- That the value of EPA's current RfD for methylmercury, 0.1 micrograms per kilogram of body weight per day, is a scientifically justifiable level for the protection of public health.
- Developmental neurotoxicity of methylmercury is the critical endpoint for setting an RfD, and the Faroe Islands study should be used as the critical study for the derivation of the RfD.
- That estimates of a benchmark dose lower bound (BMDL) of 58 parts per billion (ppb) of mercury in cord blood (corresponding to a BMDL of 12 parts per million [ppm] of mercury in hair) is a reasonable point of departure for deriving the RfD.

- To calculate the RfD, the BMDL should be divided by uncertainty factors that take into consideration biological variability when estimating dose and methylmercury database insufficiencies. An uncertainty factor of at least 10 was supported by the NAS report.
- The NAS report recommended additional investigation into the following areas:

  1. The impact of methylmercury on the prevalence of hypertension and cardiovascular disease in the United States. Likewise, reproductive effects of methylmercury exposure are not fully understood.
  2. The relationships between low-dose exposure to methylmercury throughout the life span of humans and animals and carcinogenic, reproductive, neurological, and immunological effects.
  3. The potential for delayed neurological effects resulting from mercury remaining in the brain years after exposure.
  4. The emergence of neurological effects later in life following low-dose prenatal methylmercury exposure.
  5. The mechanisms underlying methylmercury toxicity.

Dose-Response Assessment

The NAS report (NRC, 2000) recommended that an uncertainty factor of at least 10 be used when developing an RfD from a BMDL. The committee recommended that an uncertainty factor of 2 to 3 be applied to a central tendency estimate of dose derived from maternal hair, or a factor of about 2 be applied to a central tendency estimate of dose derived from cord blood to account for interindividual pharmacokinetic variability in dose reconstruction. This recognized variability is based on the current understanding of person-to-person variability among adults in toxicokinetics of methylmercury. Because the developing nervous system is considered the critical endpoint for development of an RfD or equivalent values (*e.g.,* ATSDR's Minimal Risk Level), there is a need for additional data on toxicokinetics and variability in toxicokinetics in the pregnant woman/fetal pair. Most of the available data were developed during studies of adults, especially adult males. Pregnancy is known to introduce differences in the kinetics of methylmercury.

The adverse effects of methylmercury on neurodevelopment continues postnatally (*e.g.*, myelination, synaptogenesis, and glial cell formation). These processes, particularly myelination, continue for a number of years postnatally making the young child, as well as the fetus, vulnerable to developmental changes caused by methylmercury exposures. Methylmercury is known to be excreted in breast milk making the nursing mother/infant pair an additional sensitive population. Additional data to identify the range of variability in estimates of maternal dose and the infant dose produced by these exposures is needed. Likewise, the kinetics of methylmercury in children are fundamentally not known. As noted above, young children may have additional health changes beyond those recognized among adults.

Whether or not similar doses in adults and in children produce similar nervous system responses remains to be evaluated. Existing data from the poisoning outbreaks in Iraq and in Japan showed that children will develop the same symptoms of methylmercury poisoning similar to those developed by adults. It is unclear if children develop these responses at lower or higher doses of methylmercury than those which damage the adult nervous system. Likewise, additional research is needed to determine if there are additional endpoints, specific to postnatal exposure during childhood, associated with increasing exposure to methylmercury. 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.

Interactions with Other Chemicals, Age, and/or Forms of Mercury

Evaluation of data from the three major epidemiological studies (the Faroese, the Seychellois and the New Zealand cohorts) has been made more complex because methylmercury exposures occur from ingestion of fish. Fish contain chemicals that are beneficial to development (e.g., the omega three fatty acids) and others that are adverse to neurodevelopment (e.g., PCBs, other persistent bioaccumulative toxics such as dioxins). The understanding of how co-exposure to either the beneficial or adverse effects of these other chemicals is particularly limited in estimates of dose-response relationships. Initial data also reveal that prenatal exposure to mercury vapor causes alterations in both spontaneous and learned behavior in rodents. Co-exposure to methylmercury at levels (which by themselves did not alter these functions) served to potentiate these deficits when exposure to mercury vapor and methylmercury were combined. Additional research to evaluate the impact of co-exposures to mercury vapor (as occur from dental amalgams) and methylmercury from dietary consumption of fish are needed.

The third major area of interaction is between methylmercury exposures and age-associated changes. The NAS Committee reviewed preliminary data on the potential effects of early-developmental exposure to methylmercury on the functional status of aging animals. Data on occurrence of symptoms of survivors of Minamata disease indicated that health risks of methylmercury exposure could last a lifetime and may become exacerbated during the process of normal aging. Consequently, research is needed to determine the long-term implications of the neuropsychological and neurophysiological effects of low-level methylmercury exposures. These studies should focus on issues that include:

- Critical periods for methylmercury effects: in utero or postnatal.
- Low-level dose-response relationships.
- Methylmercury demethylation in the brain following early methylmercury exposures.
- Synergistic effects of early methylmercury exposure and mercury vapor exposures.
- Neurodegenerative disorders related to methylmercury exposures.

The NAS report also described recent studies that found associations between exposure to methylmercury and impairments in the immune, reproductive, and cardiovascular systems. Both prenatal and postnatal exposures to methylmercury have been associated with immunological and cardiovascular changes. Levels of methylmercury exposure associated with these effects are as low as those producing adverse neurodevelopmental effects. In some cases, the exposures are even lower than those producing neurodevelopmental changes. Research using animal models and human populations having chronic, low-dose exposures to methylmercury is needed.

Although the developing nervous system is more sensitive to methylmercury than is the adult nervous system, the NAS report also questioned long held interpretations of blood and hair concentrations of methylmercury associated with adverse neurological effects. Recommendations on tolerable exposures for adults (e.g., EPA's pre-1994 RfD of 0.3 micrograms per kilogram of body weight per day, FDA's tolerable exposures, and the World Health Organizations [WHO] limits) are based on the assumption that paresthesias are the critical effect. Research carried out in the past decade have identified adverse effects (including changes in visual field, neuromotor disturbances, visual and auditory conduction velocities) at exposures less than those associated with paresthesias. Additional analysis of dose-response to methylmercury among adults is needed.

Human Exposures

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). Development of the nervous system postnatally includes processes (among others, myelination) that are adversely affected by methylmercury; however, it is uncertain how different exposure-response is for the young child in comparison with the fetus or the adult. Children may have different patterns of tissue distribution of mercury and methylmercury (i.e., biokinetic patterns) than adults. For these reasons, determining the dose-response to postnatal mercury and methylmercury exposures among children is critical.

Consumption of fish and marine birds and mammals represents more than 95 percent of the human intake of methylmercury. Within the United States, individual consumption of fish and seafood is highly variable. Approximately 1 to 2 percent of the U.S. population report eating fish daily, whereas about 10 percent rarely consume fish. The Mercury Study Report to Congress (EPA, 1997a) conducted extensive analyses of fish consuming habits and patterns among the general U.S. population and high-risk 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 high-end fish consumers. This work would examine specific biomarkers of mercury and methylmercury exposures (e.g., blood-mercury concentrations and hair-mercury concentrations).

Part of a strategy to meet the need for biomonitoring for mercury in the general population will be met by inclusion of blood and hair mercury analyses in the fourth National Health and Nutrition Examination Survey (NHANES IV). This survey will be large enough to produce estimates of the upper percentiles of mercury tissue levels in the general populations of women of child-bearing age and children. The survey will include dietary questions on type and frequency of fish consumption. Due to its statistical design, however, it will not be able to estimate the distribution of hair and blood mercury levels in highly exposed sub-populations including: Alaskan Natives, some Native American tribes, and people of Asian descent, as well as subsistence and sport fishers and their families, and others who consume large amounts of fish (e.g., some following "health conscious" diets). While data from similar populations in Canada will be useful in this connection, research is needed to fill this data gap because the Canadian data are largely focused on groups such as Native Canadians and subsistence fishers in remote locations.

5.9.1.2 Program Relevance

The practical importance of a separate pediatric RfD results from higher exposures (on a micrograms per kilogram of body weight per day basis) to methylmercury among children rather than adults. If children are both vulnerable and more highly exposed relative to body weight than are adults, children as well as the maternal-fetal pair are an important subpopulation. Identifying of which is of greatest concern includes factors such as the size of the population, severity of the effect, and relative vulnerability. 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 0.1 micrograms per kilogram of body weight per day basis) of the young child. If research subsequently demonstrates that additional organ systems (*e.g.,* immunotoxiocity) are adversely affected at lower doses of mercury than is the case for neuro-developmental and neuro-behavioral changes, it may be necessary to revise the RfD to protect against immunotoxiocity. Likewise, it may be of overall importance to understanding at-risk populations and to reassess what hair and blood mercury levels are associated with lower exposures than those producing paresthesia, long held to be the most sensitive adverse effect in adults.

Estimating the size of the "at risk" human population for methylmercury exposure requires data on how much methylmercury people consume from fish and seafood. Data on geographically determined variability in the concentrations of methylmercury in fish and 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 populations.

The Children's Health Executive Order 13045 (Federal Register, 1997) 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 at least 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.

5.9.1.3 Prioritized Research Needs

- *Improved understanding of mechanisms of developmental neurotoxicity from methylmercury.*
- *Improved understanding of persistent and delayed neurotoxicity resulting from developmental exposures to methylmercury.*
- *Identification of impacts from aggregate exposures and synergistic effects of methylmercury and other pollutants.*
- *Improved understanding of the modulation of immune system response from methylmercury exposure.*
- *Improved understanding of the effects on cardiovascular function as a result of methylmercury exposure.*
- *Biological monitoring for model development and improvement.*
- *Development of toxicokinetic data on methylmercury tissue distribution.*

Improved understanding of mechanisms of developmental neurotoxicity from methylmercury. A need exists to understand the 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 of 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). Mechanistic understanding will be highly important in determining the duration of exposure that is associated with adverse neurodevelopmental effects. Specifically, current concepts of RfDs are that these levels are safe if consumed over a lifetime. However, developmental windows of vulnerability are such that far shorter time periods (i.e., days, weeks) may be highly significant. Consequently, developmental RfDs may be far more briefer than life-time exposures. Mechanistic understanding will also contribute to clarifying co-exposure to other neurotoxicants, especially inorganic mercury, may need to be considered in determining tolerable exposures to methylmercury.

Improved understanding of persistent and delayed neurotoxicity resulting from developmental exposures to methylmercury. Another area of concern is the onset or exacerbation of neurological deficits in aging populations exposed *in utero* or as children. There are indications of this in the follow-up studies of the Minamata population wherein there is evidence that neurological dysfunction among people who have been exposed to methylmercury becomes exacerbated with aging. This heightened diminution of function is greater than that attributable to either age or methylmercury exposure alone. Animal studies lend support to the conclusion that methylmercury can have delayed effects that are uncovered with age. Mice exposed during gestation and lactation to methylmercury who were normal at birth developed deficits in exploratory behavior and swimming ability at 1 month, and neuromuscular and immune effects as the animals reached 1 year of age. Monkeys exposed developmentally to methylmercury developed motor incoordination when they reached middle age. Monkeys exposed *in utero* and postnatally exhibited hearing deficits in middle age, which grew relatively worse during old age compared to controls, providing evidence for an interaction of aging and methylmercury exposure on auditory impairment. All of these observations are consistent with a hypothesis that early life or *in utero* exposure to methylmercury can have adverse long-term sequelae that may not be detected in childhood. It further suggests that exposure in adulthood that results in signs of mercury toxicity can result in an exacerbation of the effects of aging. Both mechanistic and descriptive studies are needed to understand the basis of these effects, and at what body burden they occur.

Identification of impacts from aggregate exposures and synergistic effects of methylmercury and other pollutants. A need exists to identify the risk assessment uncertainties following aggregate exposure to developmental neurotoxins. An improved mechanistic understanding of the developmental neurotoxicity of methylmercury is needed to assist in understanding the 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.

Improved understanding of the modulation of immune system response from methylmercury exposure. A need exists to improve the Agency's understanding of the toxicity of mercury and methylmercury to additional organ systems. 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 which need to be addressed: 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 exposed 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 subpopulations that are particularly sensitive to the immunotoxic effects of mercury is limited and 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, and is the developing immune system particularly vulnerable? How can experimental animal research and epidemiology studies be linked to improve the risk assessment process?

Improved understanding of the effects on cardiovascular function as a result of methylmercury exposure. There are some human data linking cardiovascular effects with exposure to elemental, inorganic, and organic forms of mercury. In addition, there are two recently published studies that show an association between low-level methylmercury exposure and cardiovascular effects. In a study of Faroese children, diastolic and systolic blood pressures increased as the cord-blood mercury increased from 1 to 10 μg/L. I a study in Finland, men with hair mercury 2 ppm or higher, had a 2.0 times greater risk of acute myocardial infarction than the rest of the study population. Relatively subtle effects of methylmercury on cardiovascular indices may have public health implications. As demonstrated with lead exposure, even a small elevation in blood pressure results in an increase in both myocardial infarctions and deaths.

Biological monitoring for model development and improvement. There is a need to conduct biological monitoring of sensitive 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 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 need to be collected in a way that permits the 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 on methylmercury tissue distribution. 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 form the basis of a toxicokinetic model for predicting changes in risk from changes in the amount of exposures to mercury and methylmercury.

5.9.1.4 Research Results

Results from this research will be factored into refined mercury human health risk assessments that will be used to support future policy decisions on safe mercury levels for susceptible populations. Using these refined risk assessments, the Office of Air and Radiation (OAR) and the Office of Water (OW) will be able to make improved regulatory decisions on mercury atmospheric emissions and provide more informed guidance on methylmercury in water bodies. This work will also assist States and Regions in deciding when fish consumption advisories are needed to protect public health from methylmercury.

5.9.1.5 Measures of Success

Researchers hope to advance the following:

- A sufficient understanding of the 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 population at greatest risk from methylmercury exposures.
- An improved determination concerning the relative sensitivity of neurotoxic, immunotoxic, and cardiovascular effects.
- Improved understanding of the mechanism of delayed neurotoxicity, and the body burden at which it occurs
- 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.

5.9.1.6 Preliminary Performance Goals

GPRA performance goals have been identified for the human health effects and exposure research area based on the above Measures of Success; they are preliminary in nature and will be revised and adjusted as part of the implementation of the *Mercury Research Strategy*. ORD anticipates that completion of the *MRS* will take approximately five to ten years depending on funding levels and any adjustments for changing Program Office and Regional needs. A preliminary set of performance goals is offered below. The performance goals are:

- By 2005, identify the impacts from aggregate exposures and synergistic relationships among other commonly occurring environmental pollutants (e.g., dioxin, PCBs, dibenzofurans).
- By 2007, establish the relationships between low-dose exposure to methylmercury throughout the life span of humans and animals and carcinogenic, reproductive, neurological, and immunological effects.
- By 2009, establish the relationships among delayed neurological effects after years of methylmercury exposure, especially any effects as a result of low-dose prenatal exposures.
- By 2009, provide toxicokinetic models that describe the underlying toxicity of methylmercury to a variety of susceptible populations.

5.10 RISK COMMUNICATION

5.10.1 Key Scientific Question

> *What are the most effective means for informing susceptible populations of the health risks posed by mercury and methylmercury contamination of fish and seafood?*

5.10.1.1 Background

EPA anticipates a long lag time in controlling environmental levels of methylmercury, a known neurotoxin. If all current anthropogenic emissions of mercury ceased immediately, humans would still be exposed to elevated methylmercury levels in fish and seafood for a number of years. This lag from control of anthropogenic sources to measurable reductions in environmental mercury contaminant levels is the result of global mercury cycling from natural and re-emitted sources. Regardless of the time it takes to see meaningful reductions of mercury in both fish and humans as emissions are reduced, EPA must clearly communicate the facts on mercury and methylmercury to those exposed. In particular, the Agency needs to effectively communicate the nature and extent of risks to human health posed by methylmercury fish and seafood contamination to members of susceptible populations.

Susceptible populations include people consuming above-average amounts of fish (*e.g.,* more than approximately 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, recreational anglers and their families. People who are subsistence fishers may be a particularly important population with respect to methylmercury exposures. 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 adult neurological functioning. Consequently, women of childbearing age, maternal/fetal pairs, nursing mother/infant pairs, and young children are all included as susceptible populations. Because brain development continues during early childhood, young children, along with pregnant/nursing mothers, need to be aware of the health hazards posed by ingestion of an excessive amount of methylmercury from fish and seafood.

5.10.1.2 Program Relevance

The Agency works with various communities and exposed populations to inform them of the dangers they face from environmental contaminants. This philosophy of community involvement forms the basis for fish advisory programs supported by EPA and run by state and local organizations and governments. As noted earlier, EPA anticipates a long lag time in reducing environmental levels of methylmercury once anthropogenic mercury sources are controlled. Better-informed populations and individuals need information delivered in a way that helps them understand the magnitude of methylmercury exposures produced by particular patterns of fish consumption. An adequate research base is needed to effectively inform populations at risk of their potential exposures. Exposure data and the effectiveness of its delivery provides useful dose-response information to assist in making informed choices on fish and seafood consumption. There are several research needs related to risk communication. 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 methylmercury bioaccumulation patterns in fish. Consequently there is a need for monitoring data on mercury and methylmercury levels in water bodies and in fish. These data provide specific information to individuals and groups consuming fish from these water bodies.

5.10.1.3 Prioritized Research Needs

- *Synchronization of fish consumption advisory messages for methylmercury.*
- *Improved understanding of exposure patterns in targeting of risk messages.*
- *Increased use of risk information in making decisions about methylmercury exposures.*

Synchronization of fish consumption advisory messages for methylmercury. Research on how individual states have arrived at their fish advisory decisions is needed. Current state advisories on fish consumption use a variety of health-based approaches in setting advisory levels. Although all of these values are based on methylmercury concentrations in fish, some use EPA's RfD, some use ATSDR's 1999 revision of the Minimal Risk Level (MRL), and some use FDA's Action Level. In view of the National Academy of Science support for EPA's RfD as the appropriate level for protection of public health, the development of a synchronized strategy to communicate risk is preferred to the current approach.

Improved understanding of exposure patterns in targeting of risk messages. Data on the distribution patterns of fish consumption is needed. The Agency is concerned about risks resulting from exposure to methylmercury from multiple sources. For example, certain populations may consume both locally caught and commercial fish. Both of these sources of fish may be contaminated with methylmercury resulting in additive exposures. In the past, risk communications from the Agency have focused almost exclusively on locally caught fish. By contrast, several states include commercial fish in their advisories. A challenge for the Agency is to develop approaches to communicate risk from methylmercury in both commercially available and locally caught fish.

In developing risk communication materials, an analysis of data on how much mercury populations are exposed to from fish is needed to provide a better basis for alerting individuals and groups about their level of risk from methylmercury exposures. A recommendation for obtaining data on human exposure to methylmercury from fish is also made under the human health effects and exposure key scientific question. Specifically, data are needed to describe the distribution of mercury concentrations in locally caught and commercially available fish are required in order to accurately inform susceptible populations of their total exposure to methylmercury. Data needs include the distribution of patterns of fish consumption.

Increased use of risk information in making decisions about methylmercury exposures. An additional risk communication research need is understanding how people use risk information to make informed decisions regarding methylmercury exposures. This is particularly complex because the populations at greatest risk (*e.g.,* infants, young children) have not reached a level of cognitive development to permit such choices. The individuals or groups to reach are parents or other responsible people. This area of risk communication has rarely been explored and represents a major opportunity for EPA to play an effective role in its development. Populations at highest risk of methylmercury exposure from eating fish include some immigrant groups (*e.g.,* persons of Asian and Pacific Island ethnicity), specific Native American tribes, individuals who may be pursuing a "healthy diet" (*e.g.* a diet high in polyunsaturated fatty acids to reduce the risk of cardiovascular disease), as well as individuals who simply prefer not to consume red meat. Because the motivations of these various individuals and groups differ markedly, research on how to communicate risk is likely to vary greatly also. Research is needed on how to successfully communicate the risk of methylmercury to such divergent populations, groups and individuals. Such messages are complex for two additional reasons: (a) the health benefits of fish consumption, and (b) differences in mercury concentrations in fish depending on species, size, and geographic location.

5.10.1.4 Research Results

Results from this research will contribute to a risk communication program for methylmercury in several ways. There is a need to synchronize fish consumption advisory messages for the numerous states in which they are issued. An understanding of how states have chosen to make fish advisory decisions would be an essential element of any synchronization effort. An improved understanding of exposure patterns (*e.g.,* amount of fish consumed, types of fish consumed, frequency of consumption) will assist in targeting populations and the messages those populations receive regarding methylmercury exposure based on fish consumption. This work will assist Program Offices and Regions, state and local governments, and other public and private groups in providing more effective risk information on methylmercury exposures.

5.10.1.5 Measures of Success

Researchers hope to advance the following:

- Mapped distribution of mercury levels in fish found in all waterways of the United States.
- Identification of the risk communication styles utilized by women of childbearing age from ethnically-diverse populations.
- Identification of the populations (based on ethnic, racial, economic, tribal groups) of greatest concern with regard to ingestion of methylmercury from fish and seafood.
- Development of fish advisories of proven effectiveness that reach 90 percent of the at-risk population.
- Development of a consistent state advisory system based on the use of EPA's RfD which was judged by the National Academy of Sciences Committee to be the scientifically justifiable value for protection of public health.
- Development, with appropriate professional groups (*e.g.,* obstetricians, state medical officers, state fishery experts), of risk messages aimed at informing particular sub-populations.
- Focus group testing of risk messages to multi-cultural, multi-ethnic groups of women of child-bearing age to determine how to promote changes in fish consumption behavior.
- Utilization of multimedia sources of risk information (*e.g.*, web-based and other electronic media).

5.10.1.6 Preliminary Performance Goals

GPRA performance goals have been identified for the risk communication research area based on the above Measures of Success; they are preliminary in nature and will be revised and adjusted as part of the implementation of the *Mercury Research Strategy*. ORD anticipates that completion of the *MRS* will take approximately five to ten years depending on funding levels and any adjustments for changing Program Office and Regional needs. A preliminary set of performance goals is offered below for the risk communication research area. The performance goals are:

- By 2005, describe risk communication styles for those populations with the greatest exposure to methylmercury in fish and seafood.
- By 2007, determine the best methods of communicating risk from methylmercury in fish and risk management

opportunities for mercury reduction, both domestically and internationally.

1. 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. Mercury use appears to be growing in many other countries, especially developing nations, where their releases are often poorly controlled. International sources may have more significant releases to the global mercury pool than those from the United States. The Agency is developing an international mercury strategy into which the results of research described in this section will feed. (Unless otherwise stated, all discussions in this section deal with the use and release of mercury in the United States.)