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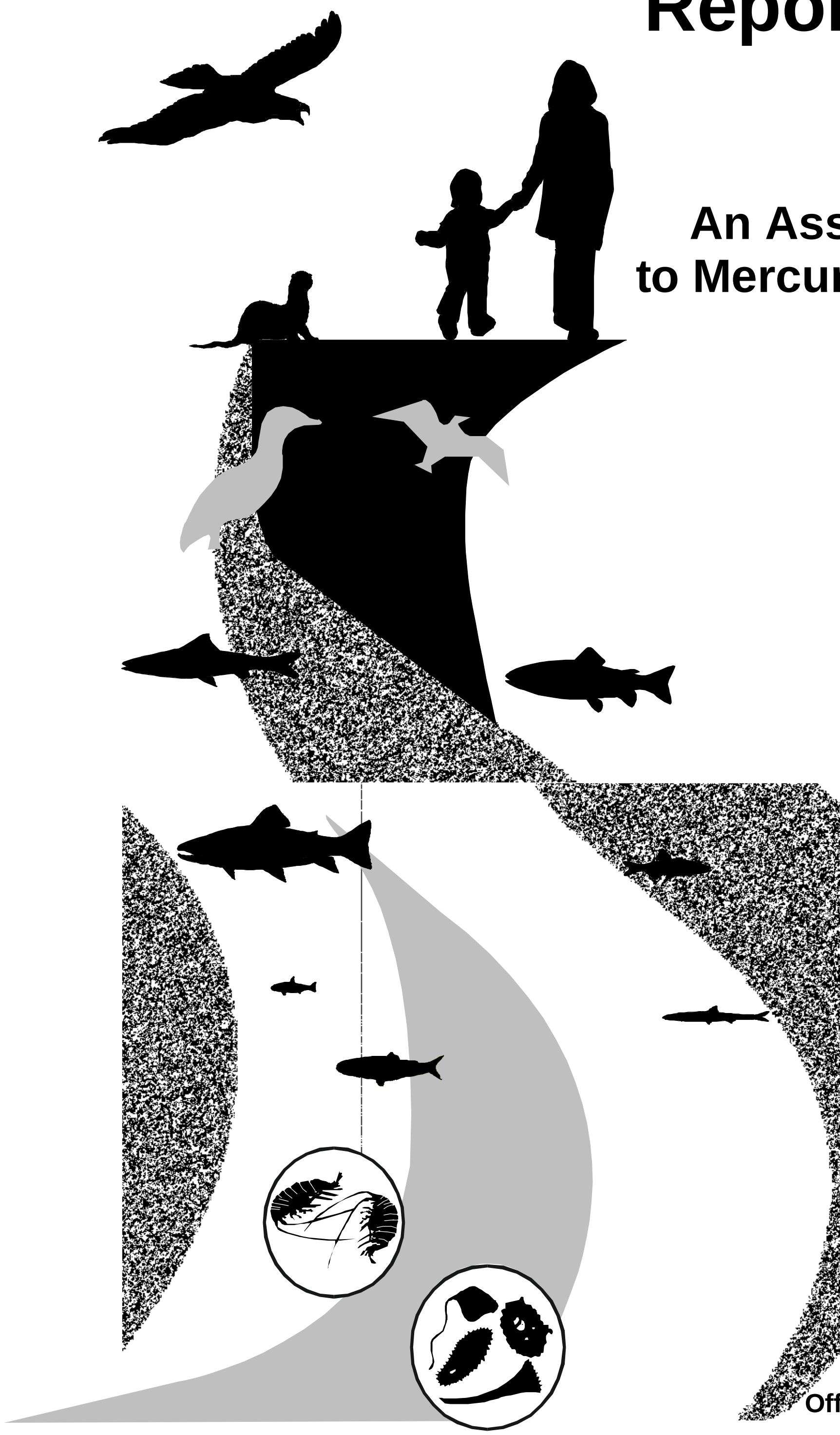
Volume IV: An Assessment of Exposure to Mercury in the United States



Office of Air Quality Planning & Standards
and
Office of Research and Development

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MERCURY STUDY REPORT TO CONGRESS

VOLUME IV:

AN ASSESSMENT OF EXPOSURE TO MERCURY IN THE UNITED STATES

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and
Office of Research and Development

U.S. Environmental Protection Agency

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LIST OF SYMBOLS, UNITS AND ACRONYMS

AC	Activated carbon
APCD	Air pollution control device
ASME	American Society of Mechanical Engineers
CAA	Clean Air Act as Amended in 1990
CaS	Calcium sulfide
cf	Cubic feet
CFB	Circulating fluidized bed
cm	Cubic meter
CRF	Capital recovery factor
dscf	Dry standard cubic feet
dscm	Dry standard cubic meter
ESP	Electrostatic precipitator
DSI	Dry sorbent injection
EPRI	Electric Power Research Institute
FFDCA	Federal Food, Drug, Cosmetic Act
FFs	Fabric filters
FGD	Flue gas desulfurization
FIFRA	Federal Insecticide, Fungicide, Rodenticide Act
FWS	U.S. Fish and Wildlife Service
GACT	Generally available control technology
GLFCATF	Great Lakes Fish Consumption Advisory Task Force
GLNPO	Great Lakes National Program Office
g	Gram
gr	Grains
HAPs	Hazardous air pollutants
HCl	Hydrochloric acid
Hg	Mercury
HgCl	Mercuric chloride
HgI	Mercuric iodide
HgO	Mercuric oxide
HgS	Mercuric sulfide
HgSe	Mercuric selenite
HMTA	Hazardous Materials Transportation Act
HVAC	Heating, ventilating and air conditioning
IDLH	Immediately dangerous to life and health
INGAA	Interstate Natural Gas Association Of America
kg	Kilogram
kW	Kilowatt
MACT	Maximum achievable control technology
MB	Mass burn
MCL	Maximum contaminant level
Mg	Megagram
MSW	Municipal solid waste
MW	Megawatt
MWCs	Municipal waste combustors

LIST OF SYMBOLS, UNITS AND ACRONYMS (continued)

MWIs	Medical waste incinerators
NaCl	Sodium chloride
NaOH	Sodium hydroxide
ng	Nanogram
NIOSH	National Institute for Occupational Safety and Health
Nm^3	Normal cubic meter
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSP	Northern States Power
NSPS	New source performance standard
OAQPS	Office of Air Quality Planning and Standards (U.S. EPA)
OECD	Organization for Economic Co-operation and Development
O&M	Operation and maintenance
OSHA	Occupational Safety and Health Administration
PCBs	Polychlorinated biphenyls
PELs	Permissible exposure limits
PM	Particulate matter
ppm	parts per million
ppmv	parts per million by volume
RQ	Reportable quantity
SARA	Superfund Amendments and Reauthorization Act
scf	Standard cubic feet
scm	Standard cubic meter
SD	Spray dryer
SDAs	Spray dryer absorbers
TCC	Total capital cost
TCLP	Toxicity characteristic leaching procedure
TMT	Trimercapto-s-triazine
tpd	Tons per day
TRI	Toxic Release Inventory
µg	Microgram
UNDEERC	University of North Dakota Energy and Environmental Research Center
WS	Wet scrubber
WW	Waterwall

EXECUTIVE SUMMARY

Section 112(n)(1)(B) of the Clean Air Act (CAA), as amended in 1990, requires the U.S. Environmental Protection Agency (U.S. EPA) to submit a study on atmospheric mercury emissions to Congress. The sources of emissions that must be studied include electric utility steam generating units, municipal waste combustion units and other sources, including area sources. Congress directed that the Mercury Study evaluate many aspects of mercury emissions, including the rate and mass of emissions, health and environmental effects, technologies to control such emissions, and the costs of such controls.

In response to this mandate, U.S. EPA has prepared an eight-volume Mercury Study Report to Congress. This document is the exposure assessment (Volume IV) of the Mercury Study Report to Congress. The exposure assessment is one component of the risk assessment of U.S. anthropogenic mercury emissions. The analysis in this volume builds on the fate and transport data compiled in Volume III of the study. This exposure assessment considers both inhalation and ingestion exposure routes. For mercury emitted to the atmosphere, ingestion is an indirect route of exposure that results from mercury deposition onto soil, water bodies and plants and uptake through the food chain. The analyses in this volume are integrated with information relating to human and wildlife health impacts of mercury in the Risk Characterization Volume (Volume VII) of the Report.

National Assessment of Mercury Exposure from Fish Consumption

A current assessment of U.S. general population methylmercury exposure through the consumption of fish is provided in this volume. This assessment was conducted to provide an estimate of mercury exposure through the consumption of fish to the general U.S. population. It is not a site-specific assessment but rather a national assessment. This assessment utilizes data from the Continuing Surveys of Food Intake by Individuals (CSFII 89-91, CSFII 1994, CSFII 1995) and the third National Heath and Nutrition Examination Survey (NHANES III) to estimate a range of fish consumption rates among U.S. fish eaters. Both per capita and per user (only individuals who reported fish consumption) were considered. For each fish-eater, the number of fish meals, the quantities and species of fish consumed and the self-reported body weights were used to estimate mercury exposure on a body weight basis. The constitution of the survey population was weighted to reflect the actual U.S. population. Results of smaller surveys on “high-end” fish consumers are also included.

These estimates of fish consumption rates were combined with fish species-specific mean values for measured mercury concentrations. The fish mercury concentration data were obtained from the National Marine Fisheries Service, Bahnick et al., (1994), and Lowe et al., (1985). Through the application of specific fish preparation factors (USDA, 1995), estimates of the range of methylmercury exposure from the consumption of fish were prepared for the fish-consuming segment of the U.S. population. Per kilogram body weight estimates of methylmercury exposure were determined by dividing the total daily methylmercury exposure from this pathway by the self-reported body weights.

Estimates of month-long patterns of fish and shellfish consumption were based on the data reporting frequency of fish/shellfish consumption obtained in the third National Health and Nutrition Examination Survey (NHANES III) conducted between 1988 and 1994. Combining these frequency data with other information on respondents in NHANES III (i.e., 24-hour recall data and self-reported body weight of subjects), and mean mercury concentrations in fish/shellfish, these projected month-long estimates of fish/shellfish consumption describe moderate-term mercury exposures for the general United States population.

Conclusions

The following conclusions are presented in approximate order of degree of certainty in the conclusion, based on the quality of the underlying database. The conclusions progress from those with greater certainty to those with lesser certainty.

- Consumption of fish is the dominant pathway of exposure to methylmercury for fish-consuming humans. There is a great deal of variability among individuals in these populations with respect to food sources and fish consumption rates. As a result, there is a great deal of variability in exposure to methylmercury in these populations. The anthropogenic contribution to the total amount of methylmercury in fish is, in part, the result of anthropogenic mercury releases from industrial and combustion sources increasing mercury body burdens in fish. As a consequence of human consumption of the affected fish, there is an incremental increase in exposure to methylmercury.

- The critical variables contributing to these different outcomes in measuring exposures are these:

  a) the fish consumption rate;

  b) the body weight of the individual in relation to the fish consumption rate;

  c) the level of methylmercury found in different fish species consumed; and

  d) the frequency of fish consumption.

- The results of the current exposure of the U.S. population from fish consumption indicate that most of the population consumes fish and is exposed to methylmercury as a result. Approximately 85% of adults in the United States consume fish and shellfish at least once a month with about 40% of adults selecting fish and shellfish as part of their diets at least once a week (based on food frequency data collected among more than 19,000 adult respondents in the NHANES III conducted between 1988 and 1994). This same survey identified 1-2% of adults who indicated they consume fish and shellfish almost daily.

- In the nationally-based dietary surveys, the types of fish most frequently reported to be eaten by consumers are tuna, shrimp, and Alaskan pollock. The importance of these species is corroborated by U.S. National Marine Fisheries Service data on per capita consumption rates of commercial fish species.

- National surveys indicate that Asian/Pacific Islander-American and Black-American subpopulations report more frequent consumption of fish and shellfish than other survey participants.

- Superimposed on this general pattern of fish and shellfish consumption is freshwater fish consumption, which may pose a significant source of methylmercury exposure to consumers of such fish. The magnitude of methylmercury exposure from freshwater fish varies with local consumption rates and methylmercury concentrations in the fish. The modeling exercise indicated that some of these methylmercury concentrations in freshwater fish may be elevated as a result of mercury emissions from anthropogenic sources. Exposures may be elevated among some members of this subpopulation; these may be evidenced by analyses of blood mercury showing concentrations in excess of 10 micrograms per liter (µg/L) that have been reported among multiple freshwater fish-consumer subpopulations.

- The results of the assessment of current exposure of the U.S. population from fish consumption as described in this volume. Exposure to methylmercury from contaminated fish results in an incremental increase in mercury exposure for most U.S. fish-consumers. Methylmercury exposure rates on a per body weight basis among fish-consuming children are predicted to be higher than for fish-consuming adults. The 50th percentile exposure rate among fish-consuming children under the age of 10 and younger is approximately 0.3 µg/kg of body weight per day. The 90th percentile predicted exposures are approximately three times greater or 0.8-1.0 µg/kg body weight/day. The predicted average exposure among males and females fish consumers of reproductive age is 0.1 µg of methylmercury/ kg body weight/day. Given that these are one-day estimates, it would be inappropriate to compare these values to the RfD except for subpopulations that eat fish/shellfish almost every day. Fish consumption rates by adult men and women vary from zero to more than 300 grams per day. These predictions are consistent across the three major contemporary national food consumption surveys.

- Estimated month-long patterns of fish/shellfish intake and mercury exposures indicate that fish/shellfish consumption is lowest among “White/NonHispanics” (73 grams/day), second highest among “Black/NonHispanics” (97 grams/day) and highest among the category designated as “Other” (123 grams/day). The category “Other” includes persons of Asian/Pacific Islander ethnicity, NonMexican Hispanics (typically persons of Caribbean ethnicity), Native American tribal members and Native Alaskans, and additional persons. Based on these estimates of month-long fish/shellfish consumption as the basis for determining methylmercury exposure, an estimated 9% of the general population exceeds the RfD.

  Among women of childbearing age, 7% exceeded the RfD based on month-long projections of fish/shellfish intake. Approximately 1% of women have methylmercury exposures three-to-four times the RfD. Children in the age group 3-to-6-years have higher intakes of methylmercury than do adults relative to body weight. Approximately 25% of children exceed the RfD, and 5% of children have methylmercury exposures from fish/shellfish two-to-three times the RfD (i.e., 0.29 µg/kg body weight/day).

- Blood mercury concentrations and hair mercury levels are biomarkers used to indicate exposure to mercury. Inorganic mercury exposure occur occupationally and for some individuals through ritualistic/hobby exposures to inorganic mercury. Dental restorations with silver/mercury amalgams can also contribute to inorganic mercury exposures. Methylmercury exposure is almost exclusively through consumption of fish, shellfish, and marine mammals. Occupational exposures to methylmercury are rare.

  Normative data describing blood and/or hair mercury for a population representative of the United States do not exist, however, some data are available. Blood mercury concentrations in the United States are usually less than 10 µg/L; however, blood mercury concentrations in excess of 30 µg/L have been reported and are attributed to fish consumption. Hair mercury concentrations in the United States are typically less than 1µg/g, however, hair mercury concentration greater than 10µ/g have been reported for women of childbearing age living in the United States. U.S. EPA's RfD is associated with a blood mercury concentration of 4-5 µg/L and a hair mercury concentration of approximately 1µg/g. The "benchmark" dose is associated with mercury concentrations of 44 µg/L in blood and 11.1 µg/g in hair. The "benchmark" dose for methylmercury is based on neurotoxic effects observed in Iraqi children exposed *in utero* to methylmercury.

- Specialized smaller surveys of subpopulations including anglers and Native American Tribal members indicate high fish consumption rates and elevated blood/hair mercury concentrations occur.

1. INTRODUCTION

Section 112(n)(1)(B) of the Clean Air Act (CAA), as amended in 1990, requires the U.S. Environmental Protection Agency (EPA) to submit a study on atmospheric mercury emissions to Congress. The sources of emissions that must be studied include electric utility steam generating units, municipal waste combustion units, and other sources, including area sources. Congress directed that the Mercury Study evaluate many aspects of mercury emissions, including the rate and mass of emissions, health and environmental effects, technologies to control such emissions, and the costs of such controls.

In response to this mandate, EPA has prepared an eight-volume Mercury Study Report to Congress. The eight volumes are as follows:

I. Executive Summary
II. An Inventory of Anthropogenic Mercury Emissions in the United States
III. Fate and Transport of Mercury in the Environment
IV. An Assessment of Exposure to Mercury in the United States
V. Health Effects of Mercury and Mercury Compounds
VI. An Ecological Assessment for Anthropogenic Mercury Emissions in the United States
VII. Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States
VIII. An Evaluation of Mercury Control Technologies and Costs

This document is the exposure assessment (Volume IV) of U.S. EPA's Report to Congress on Mercury. The exposure assessment is one element of the human health and ecological risk assessment of U.S. anthropogenic mercury (Hg) emissions. The exposure assessment considers both inhalation and ingestion exposure routes. For atmospheric mercury emissions, ingestion is an indirect route of exposure that results from mercury deposition onto soil, water bodies and plants and uptake through the food chain. The information in this document is integrated with information relating to human and wildlife health impacts of mercury in Volume VII of the report.

Using deposition values obtained from fate and transport models in Volume III, this assessment addresses the exposures that result from selected, major anthropogenic combustion and manufacturing sources. This volume also estimates current exposures to the general U.S. population that result from mercury concentrations in freshwater and marine fish. This volume does not address all anthropogenic emission sources, nor does it address emissions from natural sources.

Volume IV is composed of nine chapters and three appendices. The Introduction is followed by Chapter 2, which describes the approach utilized to calculate mercury exposures to humans and wildlife. Chapter 3 presents estimates of mercury exposure to individuals in the human population and wildlife. Chapter 4 describes current U.S. exposures through consumption of fish. The fish methylmercury concentrations and the human fish consumption rates were developed using measured data. Exposures through other routes such as dental amalgams and occupational scenarios are summarized in Chapter 5. The predicted human exposures are compared to biomonitoring data in Chapter 6.

Chapter 7 presents the conclusions of this Volume. Information needed for better assessment of exposure to emitted mercury and to current concentrations in media and biota is listed in Chapter 8. Finally, Chapter 9 lists all references cited in this volume.

There are four appendices to Volume IV: Exposure Parameter Justifications (Appendix A); Estimated National and Regional Populations of Women of Child-Bearing Age (Appendix B); Analysis of Mercury Levels in Fish and Shellfish (Appendix C); and Human Fish Consumption and Mercury Ingestion Distributions (Appendix D).

The assessment of human mercury exposure through the consumption of fish as described in Chapter 4 utilizes data from the continuing surveys of food intake by individuals (CSFII 89-91, CSFII 1994, CSFII 1995) and the third National Health and Nutrition Examination Survey (NHANES III). Both per capita and per user (only individuals who reported fish consumption) were considered. For each fish-eater, the number of fish meals, the quantities and species of fish consumed and the self-reported body weights were used to estimate mercury exposure on a body weight basis. The constitution of the survey population was weighted to reflect the actual U.S. population. Results of smaller surveys on "high-end" fish consumers are also included. Continuing Surveys of Food Intake by Individuals (CSFII 89-91) to estimate a range of fish consumption rates among fish eaters. For each fish-eater, the 3-day CSFII 89-91 study identified the number of fish meals, the quantities and species of fish consumed and the self-reported body weights of the consumers. The constitution of the survey population was weighted to reflect the actual U.S. population.

These estimates of fish consumption rates were combined with fish species-specific mean values for measured methylmercury concentrations. The fish methylmercury concentration data were obtained from the National Marine Fisheries Service, Bahnick et al., (1994), Lowe et al., (1985), and FDA (1995). Through the application of specific fish preparation factors (USDA, 1995), estimates of the range of methylmercury exposure from the consumption of fish were prepared for the fish-consuming segment of the U.S. population. Per body weight estimates of methylmercury exposure were determined by dividing the total daily methylmercury exposure from this pathway by the self-reported.

2. APPROACH TO EXPOSURE ASSESSMENT

This chapter summarizes the methods employed to calculate exposures of humans to anthropogenic mercury emissions. These methods utilize the predictions of the environmental fate modeling presented in Volume III. The models used for the human exposure assessment are identical to those used for the wildlife exposure assessment (Volume VI of this Report). For the human exposure modeling analysis, two hypothetical sites in the eastern and western U.S. were developed. The proximity of these sites to the source was varied to examine the effect of distance on model predictions. To account for the long-range transport of emitted mercury, the 50th and 90th percentile RELMAP atmospheric concentrations and deposition rates were included in the estimates from the local air dispersion model. To account for other sources of mercury, estimates of background concentrations of mercury were also included in this exposure assessment. Human exposure estimates were developed through the use of mathematical models and a series of assumptions about human dietary behaviors and ingestion rates. Three separate exposure sceanrios pertaining to the types and sources of foods consumed were developed. Parameters that affected hypothetical human exposure are identified in Sections 2.2 and 2.3; some of these parameters have the potential to change across scenarios. Appendix A describes the specific human exposure factors utilized in this volume.

2.1 Modeling Exposures near Mercury Emissions Sources

This section summarizes the computer models used to assess mercury exposure resulting from hypothetical local source emissions; this includes a description of the environmental fate models selected. Modeling assumptions related to the presence of "background" mercury as well as mercury transported from other regions of the U.S. are also presented. These models and modeling assumptions are used to predict exposures of hypothetical humans residing in areas around mercury emission sources.

2.1.1 Description of Computer Models

Atmospheric transport models were used to simulate the deposition of mercury at two different geographical scales (Table 2-1). A regional-scale analysis was conducted using the Regional Lagrangian Model of Air Pollution (RELMAP). RELMAP calculates annual mean air concentrations and annual mean deposition rates for each cell in a 40 km grid. This analysis covered the 48 contiguous states and was based upon a recent inventory of mercury emissions sources (presented in Volume II of this Report). The results of the RELMAP model accounted for the long-range transport of mercury emitted from anthropogenic sources.

The local-scale exposure analysis was conducted by using both RELMAP and a local air transport model, GAS-ISC3, to generate hypothetical exposure scenarios for four mercury emission source classes. GAS-ISC3 uses hourly meteorological data to estimate hourly air concentrations and deposition fluxes within 50 km of a point source. For each hour, general plume characteristics are estimated based on the source parameters (gas exit velocity, temperature, stack diameter, stack height, wind speed at stack top, atmospheric stability conditions) for that hour. GAS-ISC3 was run using one year of actual meteorological data (1989, the same meteorologic year as was utilized in the RELMAP modeling). The average annual predicted values for air concentration and deposition rates were then used as inputs for to IEM-2M model for 30 years, the assumed typical lifetime of a facility.

Table 2-1
Models Used to Predict Mercury Air Concentrations, Deposition Fluxes and Environmental Concentrations

Model	Description
RELMAP	Predicts average annual atmospheric mercury concentration and wet and dry deposition flux for each 40 km^2 grid in the U.S. due to all anthropocentric sources of mercury in the U.S. and a natural background atmospheric mercury concentration.
GAS-ISC3	Predicts average concentration and deposition fluxes within 50 km of emission source.
IEM-2M	Predicts environmental concentrations based on air concentrations and deposition rates to watershed and water body.

The IEM-2M model was used to estimate mercury levels in soil, water and biota based on both regional and local-scale estimates of atmospheric concentrations of mercury and mercury deposition. IEM-2M is composed of two integrated modules that simulate mercury fate using mass balance equations describing watershed soils and a shallow lake. IEM-2M simulates three chemical components — elemental mercury, Hg^0, divalent mercury, HgII, and methylmercury, MHg. Mass balances are performed for each mercury component, with internal transformation rates linking Hg^0, HgII, and MHg. Sources include wetfall and dryfall loadings of each component to watershed soils and to the water body. An additional source is diffusion of atmospheric Hg^0 vapor to watershed soils and the water body. Sinks include leaching of each component from watershed soils, burial of each component from lake sediments, volatilization of Hg^0 and MHg from the soil and water column, and advection of each component out of the lake.

At the core of IEM-2M are nine differential equations describing the mass balance of each mercury component in the surficial soil layer, in the water column, and in the surficial benthic sediments. The equations are solved for a specified interval of time, and predicted concentrations output at fixed intervals. For each calculational time step, IEM-2M first performs a terrestrial mass balance to obtain mercury concentrations in watershed soils. Soil concentrations are used along with vapor concentrations and deposition rates to calculate concentrations in various food plants. These are used, in turn, to calculate concentrations in animals. IEM-2M simultaneously performs an aquatic mass balance driven by direct atmospheric deposition along with runoff and erosion loads from watershed soils.

Human exposures through inhalation and ingestion of other contaminated food items (as well as soils) were also evaluated. Levels of atmospheric mercury were estimated by summing the predicted concentrations of the RELMAP and GAS-ISC3 models. Soil concentrations were derived directly from estimates of the IEM-2M model. Concentrations in green plants were estimated using soil-to-plant and air-to-plant biotransfer factors; mercury in these plants was derived from the local and regional scale air modeling as well as estimates of background mercury (Section 2.1.2). Estimates of the mercury concentrations in animal tissues and animal products are generally the product of predicted mercury concentrations in green plants and soils, animal consumption rates, and specific biotransfer factors. Mercury in these animals was derived from the local and regional scale air modeling as well as estimates of background mercury.

Mercury residues in fish were estimated by making the simplifying assumption that aquatic food chains can be adequately represented using four trophic levels. Respectively, these trophic levels are the following: level 1 - phytoplankton (algal producers); level 2 - zooplankton (primary herbivorous consumers); level 3 - small forage fish (secondary consumers); and level 4 - larger, piscivorous fish (tertiary consumers), which are eaten by humans. This type of food chain typifies the pelagic assemblages found in large freshwater lakes, and has been used extensively to model bioaccumulation of hydrophobic organic compounds (see for example Thomann, 1989; Clark et al., 1990; Gobas, 1993). It is recognized, however, that food chain structure can vary considerably among aquatic systems resulting in large differences in bioaccumulation in a given species of fish (Futter, 1994; Cabana et al., 1994a,b). The second simplifying assumption utilized in this effort was that methylmercury concentrations in fish are directly proportional to dissolved methylmercury concentrations in the water column. It is recognized that this relationship can vary widely among both physically similar and dissimilar water bodies.

Methylmercury concentrations in fish were derived from predicted water column concentrations of dissolved methylmercury by using BAFs for trophic level 4 fish (Table 2-2). The BAFs selected for these calculations were estimated from existing field data. The BAF (dissolved methylmercury basis) for trophic level 4 fish is 1.6×10^6. Methylmercury was estimated to constitute 7.8% of the total dissolved mercury in the water column, and 65% of this was assumed to be freely dissolved. The technical basis for these estimates is presented in Volume III, Appendix D. The potential variability around these predicted fish residue values is highlighted in Table 2-2. Percentile information for the BAF estimates are presented.

Table 2-2
Percentiles of the Methylmercury Bioaccumulation Factor

Parameter	Percentile of Distribution				
	5th	25th	50th	75th	95th
Trophic 4 BAF	$3.3\text{x}10^6$	$5.0\text{x}10^6$	$6.8\text{x}10^6$	$9.2\text{x}10^6$	$1.4\text{x } 10^7$

2.1.2 Estimates of Background Mercury

In Volume III of this Report it was noted that mercury was a constituent of the environment and has always been present on the planet. Estimates of atmospheric mercury concentrations and deposition rates from periods pre-dating large-scale anthropogenic emissions ("pre-anthropogenic") and from current data were presented for hypothetical eastern and western sites. These estimates were used as inputs to the IEM-2M model. The equilibrium results of the IEM-2M model were calculated for both the eastern and western sites and for both the pre-anthropogenic and current time periods. (Chemical equilibrium is defined here as "a steady state, in which opposing chemical reactions occur at equal rates." (Pauling, 1963)). When modeling the pre-anthropogenic period, the initial conditions of all model compartments except the atmosphere were set to a mercury concentration of zero. The results of running the pre-anthropogenic conditions to equilibrium in IEM-2M were used as the initial conditions for estimating the current mercury concentrations. Table 2-3 lists the estimated mercury air concentrations and deposition rates used at both hypothetical sites and for both time periods.

Table 2-3
Inputs to IEM-2M Model for the Two Time Periods Modeled

Time Period	Eastern Site		Western Site	
	Air Concentration ng/m^3	Annual Deposition Rate $\mu g/m^2/yr$	Air Concentration ng/m^3	Annual Deposition Rate $\mu g/m^2/yr$
Pre-Anthropogenic	0.5	3	0.5	1
Current*	1.6	10	1.6	2

* This time period does not reflect the potential contributions of local sources.

2.2 Description of Hypothetical Exposure Scenarios for Humans

In general, exposure scenarios are real or hypothetical situations that define the source of contamination, the potential receptor populations, the potential pathway(s) of exposure and the variables that affect the exposure pathways. Mercury exposure in this analysis was assessed for humans residing at hypothetical locations in the eastern and western United States. The fate of deposited mercury was examined in three types of settings: rural (agricultural); lacustrine (or water body); and urban. These three settings were selected because of the variety they encompass and because each is expected to provide a potentially elevated mercury concentration in environmental media of concern for human exposure; for example, elevated mercury concentrations are expected in the waters of lakes near mercury emission sources.

These exposure scenarios included the total amount of food derived from affected areas and the extent of mercury contamination of these food sources. For an exposure assessment which is meant to represent a broad base of potential exposures, it is not practical to model many different types of farms, gardens, etc. As for the rest of the study, a limited number of representative, generalized types of activities have been modeled.

2.2.1 Hypothetical Location Descriptions

Mercury exposure is assessed for humans hypothetically located at two generic sites: a humid site east of 90 degrees west longitude, and a more arid site west of 90 degrees west longitude (these are described in Volume III). Both sites were assumed to be located in relatively flat terrain. Exposure at each site was assessed for humans residing at 2.5, 10, or 25 km from the emissions source, as shown in Figure 2-1. The primary physical differences between the two hypothetical sites as parameterized included the assumed average annual precipitation rate, the assumed erosion characteristics for the watershed, and the amount of dilution flow from the water body. The eastern site had generally steeper terrain in the watershed than was assumed for the western site.

The atmospheric mercury concentration over the hypothetical western site was the sum of the 50th or 90th percentile of the RELMAP output for the entire contiguous United States west of 90 degrees west longitude and the GAS-ISC3 prediction resulting from the local source mercury emissions. Similarly, the mercury concentration over the hypothetical eastern site was the sum of the 50th or 90th percentile of the

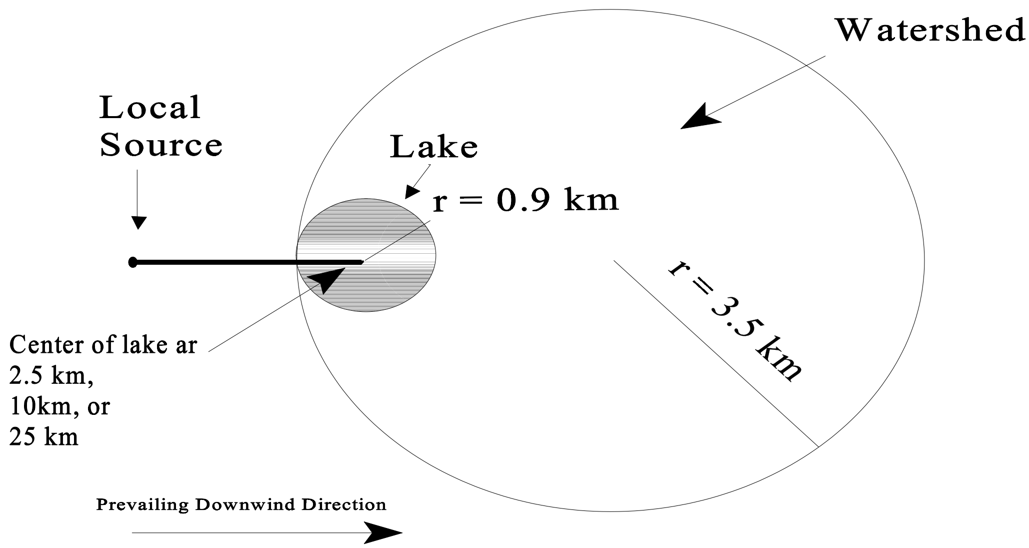

Figure 2-1
Configuration of Hypothetical Water Body and Watershed Relative to Local Source

RELMAP output for the entire contiguous United States east of 90 degrees west longitude and the GAS-ISC3 prediction resulting from the local source mercury emissions. Deposition to both sites were, similarly, the sum of the predicted depositions for GAS-ISC3 and the 50th or 90th percentile RELMAP result.

2.2.2 Description of Hypothetical Human Exposure Scenarios

Human exposure to environmental mercury is the result of mercury concentrations at specific human exposure points (e.g., ingested fish). For each location and setting, mercury exposure was estimated for individuals representing several specific subpopulations expected to have both typical and higher exposure levels. The individuals representing the subpopulations were defined to model average and high-end exposures in the three settings: rural, urban, and lacustrine. In this section each subpopulation is discussed. A more detailed description of the values chosen for parameters of the exposure assessment is given in Appendix A. Table 2-4 summarizes the hypothetical scenarios considered as well as the exposure pathways considered in each scenario.

Table 2-4
Summary of Human Exposure Scenarios

	Location											
	Rural			Urban			Lacustrine			Remote Lakes[a]		
	Subsistence Farmer		Home Gardener	Resident	Worker/High-end		High End Fisherman		Rec. angler	High End Fisherman		Rec. angler
	Adult	Child	Adult	Adult	Adult	Pica Child	Adult	Child	Adult	Adult	Child	Adult
Air inhalation	X	X	X	X	X	X	X	X	X	X	X	X
Soil ingestion	X	X	X	X	X	X	X	X	X	X	X	
Animal ingestion	X	X										
Vegetable ingestion	X	X	X		X	X	X			X		
Local fish ingestion							X	X	X	X	X	X
Local water ingestion	X	X					X	X	X			

Notes:

[a]Lakes located greater than 50 km from a mercury emission source
Blank = Pathway not considered.
X = Pathway considered.

2.2.2.1 Rural Exposure Scenarios

Both a high-end and average rural scenario were evaluated. The high-end scenario consisted of a subsistence farmer and child who consumed elevated levels of locally grown food products. It was assumed that each farm was located on a square plot of land with an area 40,000 m^2 (approximately 10 acres). The subsistence farmer was assumed to raise livestock and to consume home-grown animal tissue and animal products, including chickens and eggs as well as beef and dairy cattle. All chicken feed was assumed to be derived from non-local sources. For cattle, 100% of the hay and corn used for feed was assumed to be from the local area. It was also assumed that the subsistence farmer collected rainwater in cisterns for drinking. The typical rural dweller was assumed to raise a small garden and derive some of his food from that source.

2.2.2.2 Urban Exposure Scenarios

In the urban high end scenario, it was assumed that the person had a small garden similar in size to that of the average rural scenario. To address the fact that home-grown fruits and vegetables generally make up a smaller portion of the diet in urban areas, the contact fractions were based on weight ratios of home-grown to total fruits and vegetables consumed for city households. These fractions can be up to 10 times smaller than the values for rural households, depending on food plant type (see Table 2-4 and Appendix A). Exposure duration for inhalation was 24 hours per day. The high-end urban scenario included a pica child.

An average urban scenario consisted of an adult who worked outside of local area. The exposure duration for inhalation, therefore, was only 16 hours a day compared to the 24 hours a day for the rural and high-end urban scenarios. The only other pathway considered for this scenario was ingestion of average levels of soil.

2.2.2.3 Description of Hypothetical Human Exposure Scenarios for Individuals Using Water Bodies

The fish ingestion pathway was the dominant source of methylmercury intake in exposure scenarios wherein the fish ingestion pathway was considered appropriate. For this assessment, three human fish consumption scenarios were considered for the hypothetical lakes: (1) an adult high-end fish consumer scenario, in which an individual was assumed to ingest large amounts of locally-caught fish as well as home-grown garden produce (plant ingestion parameters identical to the rural home gardener scenario), consume drinking water from the affected water body and inhale the air; (2) a child of a high-end local fish consumer, assumed to ingest local fish, garden produce, and soil as well as inhale the affected air; and (3) a recreational angler scenario, in which the exposure pathways evaluated were fish ingestion, inhalation, and soil ingestion. These consumption scenarios were thought to represent identified fish-consuming subpopulations in the United States.

Fish for human consumption from local water bodies can be derived from many sources including self-caught, gifts, and grocery and restaurant purchases. For the purposes of this study, all fish consumed were assumed to originate from the hypothetical lakes, which were considered to represent several small lakes that might be present in the type of hypothetical locations considered. No commercial distribution of locally caught fish was assumed; exposure to locally-caught fish was modeled for the three fish-consuming subpopulations described above.

Fish consumption rates for the three fish-consuming subpopulations were derived from the Columbia River Inter-Tribal Fish Commission Report (1994). Other estimates of human fish consumption rates are reported later in this volume; these estimates highlight the broad variability in consumption rates. The Columbia River Inter-Tribal Fish Commission Report (1994) estimated fish consumption rates for members of four tribes inhabiting the Columbia River Basin. The estimated fish consumption rates were based on interviews with 513 adult tribe members who lived on or near the reservation. The participants had been selected from patient registrations lists provided by the Indian Health Service. Adults interviewed provided information on fish consumption for themselves and for 204 children under 5 years of age.

Fish consumption rates for tribal members are shown in Tables 2-5 and 2-6. The values used in this study are shown in Table 2-7. The values listed below reflect an annual average, but monthly variations were also reported. For example, the average daily consumption rate during the two highest intake months was 107.8 grams/day, and the daily consumption rate during the two lowest consumption months was 30.7 grams/day. Fish were consumed by over 90% of the surveyed population with only 9% of the respondents reporting no fish consumption. The maximum daily consumption rate for fish reported by one member of this group was 972 grams/day. Since most of the population consisted of fish consumers ("users"), utilization of per capita estimates was considered appropriate.

Table 2-5
Fish Consumption Rates for Columbia River Tribes[a]

Subpopulation	Mean Daily Fish Consumption (g/day)
Total Adult Population, aged 18 years and older	59
Children, aged 5 years and younger	20
Adult Females	56
Adult Males	63

[a] Columbia River Inter-Tribal Commission, 1994.

Table 2-6
Daily Fish Consumption Rates Among Adults
Fish Consumption by Columbia River Tribes[a]

Percentile	grams/day
50th	29-32
90th	97-130
95th	170
99th	389

[a] Columbia River Inter-Tribal Commission, 1994.

Table 2-7
Fish Consumption Rates used in this Study

Subpopulation	Fish Consumption Rate (g/day)[a]
High-end Adult	60
High-end Child	20
Recreational Angler	30

[a] Columbia River Inter-Tribal Commission, 1994.

The fish consumed by humans in both the hypothetical eastern and western sites were obtained from lakes. The drainage lakes were assumed to be circular with a diameter of 1.78 km and average depth of 5 m. A 2 cm benthic sediment depth was assumed for the lakes. The watershed area associated with each lake was 37.3 km^2.

2.3 Summary of Exposure Parameter Values

To a large degree, there are only a few parameters that vary across these scenarios. Table 2-8 categorizes exposure parameters as invariant or variant with each scenario. A complete list of the values used and rationale for these values is given in Appendix A.

Table 2-8
Potential Dependency of Exposure Parameters

Parameters Constant Across Scenarios	Parameters that Potentially Change Across Scenarios
Body weight	Fish ingestion rates
Exposure duration	Contact fractions for vegetables, animal products, and water
Inhalation rate	Contact time for inhalation
Animal and vegetable consumption rates	Child soil ingestion rates
Adult soil ingestion rates	
Drinking water ingestion rates	

Table 2-9 shows the default values for the scenario-independent parameters for both the child and adult receptors, and Table 2-10 shows the default values for the scenario-dependent exposure parameters. The technical bases for these values are in Appendix A. The hypothetical scenarios are discussed in more detail in the following sections.

Table 2-9
Default Values of Scenario-Independent Exposure Parameters

Parameter	Default Value[a]	
	Adult	**Child**
Body weight (kg)	70	17
Inhalation rate (m^3/day)	20	16
Vegetable consumption rates (g dry weight/kg body weight/day)[b]		
Leafy vegetables	0.028	0.008
Grains and cereals	1.87	3.77
Legumes	0.381	0.666
Potatoes	0.17	0.274
Root vegetables	0.024	0.036
Fruits	0.57	0.223
Fruiting vegetables	0.064	0.12
Animal product consumption rates (g dry weight/kg body weight/day)		
Beef (excluding liver)	0.341	0.553
Beef liver	0.066	0.025
Dairy	0.599	2.04
Pork	0.169	0.236
Poultry	0.111	0.214
Eggs	0.073	0.093
Lamb	0.057	0.061
Soil Ingestion rates (g/day)	0.1	Scenario-dependent
Water ingestion rate (L/day)	2	1

[a] See Appendix A for details regarding these parameter values.
[b] DW= dry weight; BW = bodyweight.

Table 2-10
Values for Scenario-Dependent Exposure Parameters[a]

Parameter	Rural Subsistence Farmer		Rural Home Gardener	Urban Scenarios			High End Fisher		Recreational Angler
	Adult	Child	Adult	Adult Resident	Home Gardener	Pica Child	Adult	Child	Adult
Fish Ingestion rates (g/day)	NA[c]	NA	NA	NA	NA	NA	60	20	30
Soil Ingestion Rate (g/day)	0.1	0.2	0.1	0.1	0.1	7.5	0.1	0.2	0.1
Contact time for inhalation (hr/day)	24	24	24	16	24	24	24	24	24
Contact fractions (unitless)									
Animal products	1	1	NA	NA	NA	NA	NA	NA	NA
Leafy vegetables	1	1	0.058	NA	0.026	NA	0.058	0.058	NA
Grains and cereals	1	1	0.667	NA	0.195	NA	0.667	0.667	NA
Legumes	1	1	0.8	NA	0.5	NA	0.8	0.8	NA
Potatoes	1	1	0.225	NA	0.031	NA	0.225	0.225	NA
Fruits	1	1	0.233	NA	0.076	NA	0.233	0.233	NA
Fruiting vegetables	1	1	0.623	NA	0.317	NA	0.623	0.623	NA
Root vegetables	1	1	0.268	NA	0.073	NA	0.268	0.268	NA
Drinking water[b]	1	1	NA	NA	NA	NA	1	1	1

[a] See Appendix A for more details regarding these values.
[b] The source of the contaminated drinking water is different for the subsistence farmer and high end fisher scenarios.
[c]NA - Not Considered to be Applicable to this assessment. For example, urban residents were assumed to eat no locally caught fish. Any fish ingested by this subpopulation was considered to be contaminated by mercury from outside the modeling domain and, thus, not considered.

Consumption rates, bioconcentration factors, and biotransfer factors may be derived based on tissue (plant, animal, and dairy) weights on either a wet or dry basis. Wet weight and dry weight are related by this formula:

$$\text{Dry Weight} = \text{Wet Weight} / (1 - \text{moisture content})$$

It is critical that parameters used together are consistent based on either dry weight or wet weight. Many plants are nearly 90% water, and a mix of wet and dry weight modeling parameters can result in a ten-fold error. The fish BAF and fish consumption rates in this Report were calculated using wet weight values. Consumption rates, plant bioaccumulation factors, and animal biotransfer factors were all based upon dry weights of tissues.

Animal and plant consumption rates as well as inhalation rates are constant across exposure scenarios. The contact fraction changes generally across the exposure scenarios. The contact fraction represents the fraction of locally-grown or affected food consumed. Typically, in exposure assessments the higher the contact fraction the greater the exposure.

2.4 Emissions Sources

Model plants (hypothetical anthropogenic mercury emissions sources) representing four source classes were developed to represent a range of mercury emissions sources. The source categories were selected for the indirect exposure analysis based on their estimated annual mercury emissions or their potential to be localized point sources of concern. The categories selected were these: municipal waste combustors (MWCs), medical waste incinerators (MWIs), utility boilers, and chlor-alkali plants. Table 2-11 shows the process parameters assumed for each of these facilities. The characteristics of the facilities were derived based on typical rather than extreme representations; the facilities are known as model plants (See Volume II).

2.5 Predicted Concentrations in Environmental Media

High rates of mercury deposition were associated with proximity to industrial sources emitting substantial levels of divalent mercury (Tables 2-12 and 2-15). Additional factors that contributed to high local deposition rates include low stack height and slow stack exit gas velocities. In general, predicted mercury concentrations in environmental media at 2.5 km were higher than levels predicted at 10 or 25 km. This was due primarily to the dilution of the mercury emissions in the atmosphere. Mercury concentrations in biota also typically demonstrated the same pattern. When the two hypothetical locations were compared (western and eastern), higher mercury concentrations were predicted to occur in the environmental media and biota at the eastern location. This was due primarily to higher levels of precipitation at the eastern site, which tends to remove mercury from the atmosphere. Also, the assumptions of background mercury are higher for the eastern than the western site. This is also attributed to the generally higher precipitation rates in the eastern United States.

Table 2-11
Process Parameters for the Model Plants Considered in the Local Impact Analysis

Model Plant	Plant Size	Capacity (% of year)	Stack Height (ft)	Stack Diameter (ft)	Hg Emission Rate (kg/yr)	Speciation Percent ($Hg^0/Hg^{2+}/Hg^P$)	Exit Velocity (m/sec)	Exit Temp. (°F)
Large Municipal Waste Combustors	2,250 tons/day	90%	230	9.5	220	60/30/10	21.9	285
Small Municipal Waste Combustors	200 tons/day	90%	140	5	20	60/30/10	21.9	375
Large Commercial HMI Waste Incinerator (Wetscrubber)	1500 lb/hr capacity (1000 lb/hr actual)	88%	40	2.7	4.58	33/50/17	9.4	175
Large Hospital HMI Waste Incinerators (Good Combustion)	1000 lb/hr capacity (667 lb/hr actual)	39%	40	2.3	23.9	2/73/25	16	1500
Small Hospital HMI Waste Incinerators (1/4 sec. Combustion)	100 lb/hr capacity (67 lb/hr actual)	27%	40	0.9	1.34	2/73/27	10.4	1500
Large Hospital HMI Waste Incinerators (Wet Scrubber)	1000 lb/hr capacity (667 lb/hr actual)	39%	40	2.3	0.84	33/50/17	9.0	175

Table 2-11 (continued)
Process Parameters for the Model Plants Considered in the Local Impact Analysis

Model Plant	Plant Size	Capacity (% of year)	Stack Height (ft)	Stack Diameter (ft)	Hg Emission Rate (kg/yr)	Speciation Percent (Hg^0/Hg^{2+}/Hg^P)	Exit Velocity (m/sec)	Exit Temp. (°F)
Small Hospital HMI Waste Incinerators (Wet Scrubber)	100 lb/hr capacity (67 lb/hr actual)	27%	40	0.9	0.05	33/50/17	5.6	175
Large Coal-fired Utility Boiler	975 Megawatts	65%	732	27	230	50/30/20	31.1	273
Medium Coal-fired Utility Boiler	375 Megawatts	65%	465	18	90	50/30/20	26.7	275
Small Coal-fired Utility Boiler	100 Megawatts	65%	266	12	10	50/30/20	6.6	295
Medium Oil-fired Utility Boiler	285 Megawatts	65%	290	14	2	50/30/20	20.7	322
Chlor-alkali plant	300 tons chlorine/ day	90%	10	0.5	380	70/30/0	0.1	Ambient

[a] Hg^0 = Elemental Mercury
[b] Hg^{2+} = Divalent Vapor Phase Mercury
[c] Hg^P = Particle-Bound Mercury

Table 2-12
Predicted Mercury Values for Environmental Media at Eastern Site (ISC3 + RELMAP 50th)

50th Percentile											
Plant	**Distance**	**Air Concentration (ng/m3)**	**%RelMap**	**%ISC**	**Total Deposition (ug/m2/yr)**	**%RelMap**	**%ISC**	**Total Hg Soil Concentration in Untilled Soil (ng/g)**	**%Background**	**%RelMap**	**%ISC**
Variant b:Large Municipal Waste Combustor	2.5 km	1.7E+00	97%	3%	4.2E+01	34%	66%	1.0E+02	46%	8%	47%
	10 km	1.7E+00	98%	2%	2.6E+01	57%	43%	7.4E+01	63%	11%	26%
	25 km	1.7E+00	99%	1%	1.9E+01	78%	22%	6.1E+01	76%	13%	11%
Variant b:Small Municipal Waste Combustor	2.5 km	1.7E+00	99%	1%	1.9E+01	74%	26%	6.3E+01	74%	12%	14%
	10 km	1.7E+00	100%	0%	1.6E+01	90%	10%	5.7E+01	82%	14%	5%
	25 km	1.7E+00	100%	0%	1.5E+01	97%	3%	5.5E+01	85%	14%	1%
Large Commercial HMI	2.5 km	1.7E+00	99%	1%	1.9E+01	76%	24%	6.2E+01	75%	12%	13%
	10 km	1.7E+00	100%	0%	1.5E+01	95%	5%	5.6E+01	84%	14%	2%
	25 km	1.7E+00	100%	0%	1.5E+01	99%	1%	5.5E+01	85%	14%	1%
Large Hospital HMI	2.5 km	1.7E+00	97%	3%	4.4E+01	33%	67%	1.1E+02	44%	7%	48%
	10 km	1.7E+00	99%	1%	2.0E+01	74%	26%	6.3E+01	74%	12%	14%
	25 km	1.7E+00	100%	0%	1.6E+01	92%	8%	5.7E+01	82%	14%	4%
Small Hospital HMI	2.5 km	1.7E+00	100%	0%	1.6E+01	88%	12%	5.8E+01	81%	13%	6%
	10 km	1.7E+00	100%	0%	1.5E+01	98%	2%	5.5E+01	85%	14%	1%
	25 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.5E+01	86%	14%	0%
Large Hospital HMI (wet scrubber)	2.5 km	1.7E+00	100%	0%	1.5E+01	94%	6%	5.6E+01	84%	14%	3%
	10 km	1.7E+00	100%	0%	1.5E+01	99%	1%	5.5E+01	85%	14%	0%
	25 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.5E+01	86%	14%	0%
Small Hospital HMI (wet scrubber)	2.5 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.5E+01	86%	14%	0%
	10 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.4E+01	86%	14%	0%
	25 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.4E+01	86%	14%	0%
Large Coal-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	3.0E+01	48%	52%	8.1E+01	58%	10%	33%
	10 km	1.7E+00	100%	0%	1.7E+01	83%	17%	5.9E+01	79%	13%	8%
	25 km	1.7E+00	100%	0%	1.6E+01	93%	7%	5.6E+01	83%	14%	3%
Medium Coal-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	2.1E+01	68%	32%	6.6E+01	71%	12%	18%
	10 km	1.7E+00	100%	0%	1.6E+01	89%	11%	5.8E+01	81%	13%	5%
	25 km	1.7E+00	100%	0%	1.5E+01	94%	6%	5.6E+01	84%	14%	3%
Small Coal-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	1.6E+01	90%	10%	5.7E+01	82%	14%	5%
	10 km	1.7E+00	100%	0%	1.5E+01	96%	4%	5.5E+01	84%	14%	2%
	25 km	1.7E+00	100%	0%	1.5E+01	99%	1%	5.5E+01	85%	14%	1%
Medium OIl-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	1.5E+01	99%	1%	5.5E+01	85%	14%	1%
	10 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.5E+01	86%	14%	0%
	25 km	1.7E+00	100%	0%	1.5E+01	100%	0%	5.5E+01	86%	14%	0%
Chlor-alkali plant	2.5 km	4.0E+00	42%	58%	2.5E+02	6%	94%	4.5E+02	10%	2%	88%
	10 km	2.1E+00	79%	21%	4.6E+01	32%	68%	1.1E+02	43%	7%	50%
	25 km	1.8E+00	92%	8%	2.2E+01	65%	35%	6.8E+01	69%	11%	20%

Table 2-13

Predicted Mercury Values for Environmental Media at Eastern Site (ISC3 + RELMAP 90th)

90th Percentile											
Plant	**Distance**	**Air Concentration (ng/m3)**	**%RelMap**	**%ISC**	**Total Deposition (ug/m2/yr)**	**%RelMap**	**%ISC**	**Total Hg Soil Concentration in Untilled Soil (ng/g)**	**%Background**	**%Rel Map**	**%ISC**
Variant b:Large Municipal Waste Combustor	2.5 km	1.8E+00	97%	3%	5.5E+01	50%	50%	1.2E+02	38%	24%	38%
	10 km	1.8E+00	98%	2%	3.8E+01	71%	29%	9.5E+01	49%	31%	20%
	25 km	1.7E+00	99%	1%	3.1E+01	87%	13%	8.3E+01	56%	35%	8%
Variant b:Small Municipal Waste Combustor	2.5 km	1.7E+00	99%	1%	3.2E+01	85%	15%	8.5E+01	55%	35%	10%
	10 km	1.7E+00	100%	0%	2.9E+01	95%	5%	7.9E+01	59%	37%	3%
	25 km	1.7E+00	100%	0%	2.8E+01	98%	2%	7.7E+01	61%	38%	1%
Large Commercial HMI	2.5 km	1.7E+00	99%	1%	3.2E+01	85%	15%	8.4E+01	55%	35%	9%
	10 km	1.7E+00	100%	0%	2.8E+01	98%	2%	7.7E+01	60%	38%	2%
	25 km	1.7E+00	100%	0%	2.7E+01	99%	1%	7.7E+01	61%	39%	0%
Large Hospital HMI	2.5 km	1.8E+00	97%	3%	5.7E+01	48%	52%	1.3E+02	37%	23%	40%
	10 km	1.7E+00	99%	1%	3.2E+01	84%	16%	8.5E+01	55%	35%	10%
	25 km	1.7E+00	100%	0%	2.8E+01	96%	4%	7.8E+01	60%	38%	3%
Small Hospital HMI	2.5 km	1.7E+00	100%	0%	2.9E+01	93%	7%	8.0E+01	59%	37%	4%
	10 km	1.7E+00	100%	0%	2.7E+01	99%	1%	7.7E+01	61%	38%	1%
	25 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
Large Hospital HMI (wet scrubber)	2.5 km	1.7E+00	100%	0%	2.8E+01	97%	3%	7.8E+01	60%	38%	2%
	10 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
	25 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
Small Hospital HMI (wet scrubber)	2.5 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
	10 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
	25 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
Large Coal-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	4.3E+01	64%	36%	1.0E+02	45%	29%	26%
	10 km	1.7E+00	100%	0%	3.0E+01	90%	10%	8.1E+01	57%	36%	6%
	25 km	1.7E+00	100%	0%	2.8E+01	96%	4%	7.8E+01	60%	38%	2%
Medium Coal-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	3.4E+01	80%	20%	8.8E+01	53%	34%	13%
	10 km	1.7E+00	100%	0%	2.9E+01	94%	6%	7.9E+01	59%	37%	4%
	25 km	1.7E+00	100%	0%	2.8E+01	97%	3%	7.8E+01	60%	38%	2%
Small Coal-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	2.9E+01	94%	6%	7.9E+01	59%	37%	3%
	10 km	1.7E+00	100%	0%	2.8E+01	98%	2%	7.7E+01	60%	38%	1%
	25 km	1.7E+00	100%	0%	2.7E+01	99%	1%	7.7E+01	61%	39%	0%
Medium OIl-fired Utility Boiler	2.5 km	1.7E+00	100%	0%	2.7E+01	99%	1%	7.7E+01	61%	39%	0%
	10 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
	25 km	1.7E+00	100%	0%	2.7E+01	100%	0%	7.6E+01	61%	39%	0%
Chlor-alkali plant	2.5 km	4.0E+00	43%	57%	2.6E+02	10%	90%	4.8E+02	10%	6%	84%
	10 km	2.2E+00	79%	21%	5.9E+01	46%	54%	1.3E+02	36%	23%	41%
	25 km	1.9E+00	92%	8%	3.5E+01	77%	23%	9.0E+01	52%	33%	15%

Table 2-14
Predicted Mercury Values in Water Column and Biota for Eastern Site
(ISC3 + RELMAP 50th)

50th Percentile											
		MHg Dissolved Water Conc.(ng/l)	**Tier 4 Fish MHg Concentration (ug/g)**	**%Background**	**%Rel Map**	**%ISC**	**Total Hg Grain Concentration (ng/g)**	**%Background**	**%Rel Map**	**%ISC**
Variant b:Large Municipal Waste Combustor	2.5 km	1.7E-01	1.1E+00	38%	7%	54%	2.1E+00	93%	3%	4%
	10 km	1.1E-01	7.6E-01	58%	11%	31%	2.1E+00	94%	3%	2%
	25 km	8.9E-02	6.0E-01	73%	14%	13%	2.1E+00	95%	3%	1%
Variant b:Small Municipal Waste Combustor	2.5 km	9.5E-02	6.4E-01	68%	13%	18%	2.1E+00	96%	3%	1%
	10 km	8.2E-02	5.6E-01	79%	15%	6%	2.1E+00	96%	3%	0%
	25 km	7.9E-02	5.3E-01	83%	16%	2%	2.1E+00	96%	3%	0%
Large Commercial HMI	2.5 km	9.6E-02	6.5E-01	68%	13%	19%	2.1E+00	96%	3%	1%
	10 km	8.0E-02	5.4E-01	82%	16%	3%	2.1E+00	96%	3%	0%
	25 km	7.8E-02	5.3E-01	83%	16%	1%	2.1E+00	97%	3%	0%
Large Hospital HMI	2.5 km	1.9E-01	1.3E+00	34%	6%	60%	2.1E+00	93%	3%	4%
	10 km	9.4E-02	6.4E-01	69%	13%	18%	2.1E+00	96%	3%	1%
	25 km	8.1E-02	5.5E-01	80%	15%	5%	2.1E+00	96%	3%	0%
Small Hospital HMI	2.5 km	8.5E-02	5.8E-01	76%	15%	9%	2.1E+00	96%	3%	0%
	10 km	7.8E-02	5.3E-01	83%	16%	1%	2.1E+00	97%	3%	0%
	25 km	7.8E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
Large Hospital HMI (wet scrubber)	2.5 km	8.1E-02	5.5E-01	80%	15%	4%	2.1E+00	96%	3%	0%
	10 km	7.8E-02	5.3E-01	84%	16%	1%	2.1E+00	97%	3%	0%
	25 km	7.7E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
Small Hospital HMI (wet scrubber)	2.5 km	7.8E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
	10 km	7.7E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
	25 km	7.7E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
Large Coal-fired Utility Boiler	2.5 km	1.3E-01	9.1E-01	48%	9%	42%	2.1E+00	96%	3%	1%
	10 km	8.6E-02	5.9E-01	75%	14%	10%	2.1E+00	96%	3%	0%
	25 km	8.0E-02	5.5E-01	81%	15%	4%	2.1E+00	96%	3%	0%
Medium Coal-fired Utility Boiler	2.5 km	1.0E-01	6.9E-01	64%	12%	24%	2.1E+00	96%	3%	0%
	10 km	8.3E-02	5.6E-01	78%	15%	7%	2.1E+00	96%	3%	0%
	25 km	8.0E-02	5.4E-01	81%	16%	3%	2.1E+00	96%	3%	0%
Small Coal-fired Utility Boiler	2.5 km	8.3E-02	5.6E-01	79%	15%	6%	2.1E+00	96%	3%	0%
	10 km	7.9E-02	5.4E-01	82%	16%	2%	2.1E+00	96%	3%	0%
	25 km	7.8E-02	5.3E-01	83%	16%	1%	2.1E+00	97%	3%	0%
Medium OIl-fired Utility Boiler	2.5 km	7.8E-02	5.3E-01	83%	16%	1%	2.1E+00	97%	3%	0%
	10 km	7.8E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
	25 km	7.7E-02	5.3E-01	84%	16%	0%	2.1E+00	97%	3%	0%
Chlor-alkali plant	2.5 km	1.0E+00	6.8E+00	6%	1%	92%	4.5E+00	44%	2%	54%
	10 km	1.8E-01	1.2E+00	37%	7%	56%	2.5E+00	79%	3%	18%
	25 km	1.0E-01	6.8E-01	65%	12%	23%	2.2E+00	90%	3%	7%

Table 2-15
Predicted Mercury Values in Water Column and Biota for Eastern Site
(ISC3 + RELMAP 90th)

		MHg Dissolved Water Conc.(ng/l)	Tier 4 Fish MHg Concentration (ug/g)	%Background	%Rel Map	%ISC	Total Hg Grain Concentration (ng/g)	%Background	%Rel Map	%ISC
Variant b:Large Municipal Waste Combustor	2.5 km	2.0E-01	1.4E+00	32%	23%	45%	2.2E+00	90%	6%	4%
	10 km	1.5E-01	9.9E-01	44%	32%	23%	2.2E+00	91%	6%	2%
	25 km	1.2E-01	8.4E-01	52%	38%	9%	2.1E+00	93%	6%	1%
Variant b:Small Municipal Waste Combustor	2.5 km	1.3E-01	8.8E-01	50%	36%	13%	2.1E+00	93%	6%	1%
	10 km	1.2E-01	8.0E-01	55%	40%	4%	2.1E+00	93%	6%	0%
	25 km	1.1E-01	7.7E-01	57%	42%	1%	2.1E+00	94%	6%	0%
Large Commercial HMI	2.5 km	1.3E-01	8.9E-01	50%	36%	14%	2.1E+00	93%	6%	1%
	10 km	1.1E-01	7.8E-01	57%	41%	2%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.7E-01	58%	42%	0%	2.1E+00	94%	6%	0%
Large Hospital HMI	2.5 km	2.3E-01	1.5E+00	29%	21%	51%	2.2E+00	90%	6%	4%
	10 km	1.3E-01	8.8E-01	50%	37%	13%	2.1E+00	93%	6%	1%
	25 km	1.2E-01	7.9E-01	56%	41%	3%	2.1E+00	93%	6%	0%
Small Hospital HMI	2.5 km	1.2E-01	8.2E-01	54%	39%	7%	2.1E+00	93%	6%	0%
	10 km	1.1E-01	7.7E-01	57%	42%	1%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
Large Hospital HMI (wet scrubber)	2.5 km	1.2E-01	7.9E-01	56%	41%	3%	2.1E+00	94%	6%	0%
	10 km	1.1E-01	7.7E-01	58%	42%	0%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
Small Hospital HMI (wet scrubber)	2.5 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
	10 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
Large Coal-fired Utility Boiler	2.5 km	1.7E-01	1.1E+00	38%	28%	34%	2.1E+00	93%	6%	1%
	10 km	1.2E-01	8.2E-01	54%	39%	7%	2.1E+00	93%	6%	0%
	25 km	1.2E-01	7.8E-01	56%	41%	3%	2.1E+00	94%	6%	0%
Medium Coal-fired Utility Boiler	2.5 km	1.4E-01	9.3E-01	48%	35%	18%	2.1E+00	93%	6%	0%
	10 km	1.2E-01	8.0E-01	55%	40%	5%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.8E-01	57%	41%	2%	2.1E+00	94%	6%	0%
Small Coal-fired Utility Boiler	2.5 km	1.2E-01	8.0E-01	55%	40%	5%	2.1E+00	94%	6%	0%
	10 km	1.1E-01	7.8E-01	57%	41%	2%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.7E-01	58%	42%	1%	2.1E+00	94%	6%	0%
Medium OIl-fired Utility Boiler	2.5 km	1.1E-01	7.7E-01	58%	42%	1%	2.1E+00	94%	6%	0%
	10 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
	25 km	1.1E-01	7.6E-01	58%	42%	0%	2.1E+00	94%	6%	0%
Chlor-alkali plant	2.5 km	1.0E+00	7.1E+00	6%	5%	89%	4.6E+00	43%	3%	54%
	10 km	2.1E-01	1.4E+00	31%	22%	47%	2.6E+00	77%	5%	18%
	25 km	1.4E-01	9.2E-01	48%	35%	17%	2.3E+00	88%	6%	6%

Table 2-16 (continued)
Predicted Mercury Values for Environmental Media at Western Site (ISC3 + RELMAP 50th)

Table 2-16
Predicted Mercury Values for Environmental Media at Western Site (ISC3 + RELMAP 50th)

50th Percentile

Plant	Distance	Air Concentration (ng/m3)	%RelMap	%ISC	Total Deposition (ug/m2/yr)	%RelMap	%ISC	Total Hg Soil Concentration in Untilled Soil (ng/g)	%Background	%RelMap	%ISC
Variant b:Large Municipal Waste Combustor	2.5 km	1.7E+00	98%	2%	2.0E+01	11%	89%	3.8E+01	20%	1%	79%
	10 km	1.6E+00	98%	2%	1.1E+01	20%	80%	2.3E+01	33%	2%	65%
	25 km	1.6E+00	99%	1%	5.6E+00	41%	59%	1.3E+01	56%	4%	40%
Variant b:Small Municipal Waste Combustor	2.5 km	1.6E+00	99%	1%	6.2E+00	38%	62%	1.4E+01	53%	4%	44%
	10 km	1.6E+00	100%	0%	3.4E+00	68%	32%	9.9E+00	76%	5%	18%
	25 km	1.6E+00	100%	0%	2.7E+00	87%	13%	8.6E+00	87%	6%	6%
Large Commercial HMI	2.5 km	1.6E+00	99%	1%	6.0E+00	38%	62%	1.4E+01	53%	4%	43%
	10 km	1.6E+00	100%	0%	2.8E+00	83%	17%	8.9E+00	85%	6%	9%
	25 km	1.6E+00	100%	0%	2.4E+00	95%	5%	8.3E+00	91%	6%	2%
Large Hospital HMI	2.5 km	1.7E+00	98%	2%	2.7E+01	9%	91%	4.8E+01	16%	1%	83%
	10 km	1.6E+00	99%	1%	5.9E+00	39%	61%	1.4E+01	54%	4%	42%
	25 km	1.6E+00	100%	0%	3.3E+00	71%	29%	9.6E+00	79%	5%	16%
Small Hospital HMI	2.5 km	1.6E+00	100%	0%	3.9E+00	59%	41%	1.1E+01	71%	5%	24%
	10 km	1.6E+00	100%	0%	2.5E+00	92%	8%	8.4E+00	90%	6%	4%
	25 km	1.6E+00	100%	0%	2.4E+00	98%	2%	8.2E+00	93%	6%	1%
Large Hospital HMI (wet scrubber)	2.5 km	1.6E+00	100%	0%	3.0E+00	77%	23%	9.2E+00	82%	6%	12%
	10 km	1.6E+00	100%	0%	2.4E+00	96%	4%	8.2E+00	92%	6%	2%
	25 km	1.6E+00	100%	0%	2.3E+00	99%	1%	8.1E+00	93%	6%	0%
Small Hospital HMI (wet scrubber)	2.5 km	1.6E+00	100%	0%	2.4E+00	98%	2%	8.2E+00	93%	6%	1%
	10 km	1.6E+00	100%	0%	2.3E+00	100%	0%	8.1E+00	93%	6%	0%
	25 km	1.6E+00	100%	0%	2.3E+00	100%	0%	8.1E+00	94%	6%	0%
Large Coal-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	5.8E+00	40%	60%	1.4E+01	55%	4%	42%
	10 km	1.6E+00	100%	0%	3.5E+00	67%	33%	9.9E+00	76%	5%	19%
	25 km	1.6E+00	100%	0%	3.3E+00	69%	31%	9.8E+00	78%	5%	17%
Medium Coal-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	4.3E+00	53%	47%	1.1E+01	66%	5%	29%
	10 km	1.6E+00	100%	0%	3.7E+00	63%	37%	1.0E+01	73%	5%	22%
	25 km	1.6E+00	100%	0%	3.2E+00	73%	27%	9.5E+00	79%	5%	15%
Small Coal-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	3.4E+00	69%	31%	9.8E+00	77%	5%	18%

Table 2-16 (continued)
Predicted Mercury Values for Environmental Media at Western Site (ISC3 + RELMAP 50th)

50th Percentile											
Plant	**Distance**	**Air Concentration (ng/m3)**	**%RelMap**	**%ISC**	**Total Deposition (ug/m2/yr)**	**%RelMap**	**%ISC**	**Total Hg Soil Concentration in Untilled Soil (ng/g)**	**%Background**	**%RelMap**	**%ISC**
	10 km	1.6E+00	100%	0%	2.8E+00	84%	16%	8.8E+00	86%	6%	8%
	25 km	1.6E+00	100%	0%	2.5E+00	94%	6%	8.3E+00	91%	6%	3%
Medium OIl-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	2.4E+00	96%	4%	8.2E+00	92%	6%	2%
	10 km	1.6E+00	100%	0%	2.4E+00	97%	3%	8.2E+00	92%	6%	1%
	25 km	1.6E+00	100%	0%	2.3E+00	99%	1%	8.1E+00	93%	6%	1%
Chlor-alkali plant	2.5 km	3.5E+00	46%	54%	1.9E+02	1%	99%	3.2E+02	2%	0%	97%
	10 km	1.9E+00	84%	16%	2.5E+01	9%	91%	4.5E+01	17%	1%	82%
	25 km	1.7E+00	94%	6%	8.1E+00	28%	72%	1.8E+01	43%	3%	54%

Table 2-17
Predicted Mercury Values for Environmental Media at Western Site (ISC3 + RELMAP 90th)

90th Percentile												
Plant	**Distance**	**Air Concentration (ng/m3)**	**%RelMap**	**%ISC**	**Total Deposition (ug/m2/yr)**	**%RelMap**	**%ISC**	**Total Hg Soil Concentration in Untilled Soil (ng/g)**	**%Background**	**%RelMap**	**%ISC**
Variant b:Large Municipal Waste Combustor	2.5 km	1.7E+00	98%	2%	2.6E+01	31%	69%	4.7E+01	16%	21%	63%
	10 km	1.7E+00	98%	2%	1.7E+01	47%	53%	3.2E+01	24%	31%	46%
	25 km	1.7E+00	99%	1%	1.1E+01	71%	29%	2.3E+01	33%	43%	24%
Variant b:Small Municipal Waste Combustor	2.5 km	1.7E+00	99%	1%	1.2E+01	67%	33%	2.4E+01	32%	41%	27%
	10 km	1.6E+00	100%	0%	9.1E+00	88%	12%	1.9E+01	39%	51%	9%
	25 km	1.6E+00	100%	0%	8.3E+00	96%	4%	1.8E+01	42%	55%	3%
Large Commercial HMI	2.5 km	1.7E+00	99%	1%	1.2E+01	68%	32%	2.3E+01	32%	42%	26%
	10 km	1.6E+00	100%	0%	8.5E+00	94%	6%	1.8E+01	42%	54%	4%
	25 km	1.6E+00	100%	0%	8.1E+00	98%	2%	1.8E+01	43%	56%	1%
Large Hospital HMI	2.5 km	1.7E+00	98%	2%	3.2E+01	25%	75%	5.7E+01	13%	17%	70%
	10 km	1.7E+00	99%	1%	1.2E+01	69%	31%	2.3E+01	32%	42%	25%
	25 km	1.6E+00	100%	0%	8.9E+00	90%	10%	1.9E+01	40%	52%	8%
Small Hospital HMI	2.5 km	1.6E+00	100%	0%	9.6E+00	83%	17%	2.0E+01	38%	49%	13%
	10 km	1.6E+00	100%	0%	8.2E+00	98%	2%	1.8E+01	43%	55%	2%
	25 km	1.6E+00	100%	0%	8.0E+00	99%	1%	1.7E+01	43%	56%	0%
Large Hospital HMI (wet scrubber)	2.5 km	1.6E+00	100%	0%	8.7E+00	92%	8%	1.9E+01	41%	53%	6%
	10 km	1.6E+00	100%	0%	8.1E+00	99%	1%	1.8E+01	43%	56%	1%
	25 km	1.6E+00	100%	0%	8.0E+00	100%	0%	1.7E+01	43%	56%	0%
Small Hospital HMI (wet scrubber)	2.5 km	1.6E+00	100%	0%	8.0E+00	99%	1%	1.7E+01	43%	56%	0%
	10 km	1.6E+00	100%	0%	8.0E+00	100%	0%	1.7E+01	44%	56%	0%
	25 km	1.6E+00	100%	0%	8.0E+00	100%	0%	1.7E+01	44%	56%	0%
Large Coal-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	1.2E+01	69%	31%	2.3E+01	33%	42%	25%
	10 km	1.6E+00	100%	0%	9.1E+00	88%	12%	1.9E+01	39%	51%	10%
	25 km	1.6E+00	100%	0%	9.0E+00	89%	11%	1.9E+01	40%	52%	9%
Medium Coal-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	1.0E+01	80%	20%	2.1E+01	37%	47%	16%
	10 km	1.6E+00	100%	0%	9.4E+00	85%	15%	2.0E+01	39%	50%	11%
	25 km	1.6E+00	100%	0%	8.9E+00	90%	10%	1.9E+01	40%	52%	8%
Small Coal-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	9.1E+00	88%	12%	1.9E+01	40%	51%	9%
	10 km	1.6E+00	100%	0%	8.5E+00	95%	5%	1.8E+01	42%	54%	4%
	25 km	1.6E+00	100%	0%	8.2E+00	98%	2%	1.8E+01	43%	56%	1%
Medium OIl-fired Utility Boiler	2.5 km	1.6E+00	100%	0%	8.1E+00	99%	1%	1.8E+01	43%	56%	1%
	10 km	1.6E+00	100%	0%	8.1E+00	99%	1%	1.7E+01	43%	56%	1%
	25 km	1.6E+00	100%	0%	8.0E+00	100%	0%	1.7E+01	43%	56%	0%
Chlor-alkali plant	2.5 km	3.6E+00	46%	54%	2.0E+02	4%	96%	3.3E+02	2%	3%	95%
	10 km	1.9E+00	84%	16%	3.0E+01	26%	74%	5.4E+01	14%	18%	68%
	25 km	1.7E+00	94%	6%	1.4E+01	58%	42%	2.7E+01	28%	36%	35%

Table 2-18
Predicted Mercury Values in Water Column and Biota for Western Site
(ISC3 + RELMAP 50th)

50th Percentile											
		MHg Dissolved Water Conc.(ng/l)	**Tier 4 Fish MHg Concentration (ug/g)**	**%Background**	**%Rel Map**	**%ISC**	**Total Hg Grain Concentration (ng/g)**	**%Background**	**%Rel Map**	**%ISC**
Variant b:Large Municipal Waste Combustor	2.5 km	8.8E-02	6.0E-01	15%	1%	84%	1.7E+00	96%	1%	3%
	10 km	5.5E-02	3.7E-01	24%	2%	74%	1.7E+00	97%	1%	2%
	25 km	2.7E-02	1.9E-01	48%	4%	48%	1.7E+00	98%	1%	1%
Variant b:Small Municipal Waste Combustor	2.5 km	3.3E-02	2.3E-01	40%	3%	57%	1.6E+00	98%	1%	1%
	10 km	1.9E-02	1.3E-01	68%	6%	26%	1.6E+00	99%	1%	0%
	25 km	1.6E-02	1.1E-01	84%	7%	9%	1.6E+00	99%	1%	0%
Large Commercial HMI	2.5 km	3.4E-02	2.3E-01	39%	3%	58%	1.6E+00	98%	1%	1%
	10 km	1.7E-02	1.1E-01	80%	7%	14%	1.6E+00	99%	1%	0%
	25 km	1.5E-02	1.0E-01	89%	8%	3%	1.6E+00	99%	1%	0%
Large Hospital HMI	2.5 km	1.4E-01	9.6E-01	9%	1%	90%	1.7E+00	95%	1%	4%
	10 km	3.1E-02	2.1E-01	42%	4%	54%	1.6E+00	98%	1%	1%
	25 km	1.8E-02	1.2E-01	73%	6%	20%	1.6E+00	99%	1%	0%
Small Hospital HMI	2.5 km	2.3E-02	1.5E-01	58%	5%	37%	1.6E+00	99%	1%	0%
	10 km	1.5E-02	1.0E-01	87%	7%	6%	1.6E+00	99%	1%	0%
	25 km	1.4E-02	9.8E-02	91%	8%	1%	1.6E+00	99%	1%	0%
Large Hospital HMI (wet scrubber)	2.5 km	1.8E-02	1.2E-01	73%	6%	20%	1.6E+00	99%	1%	0%
	10 km	1.5E-02	1.0E-01	90%	8%	3%	1.6E+00	99%	1%	0%
	25 km	1.4E-02	9.8E-02	92%	8%	1%	1.6E+00	99%	1%	0%
Small Hospital HMI (wet scrubber)	2.5 km	1.5E-02	9.9E-02	91%	8%	2%	1.6E+00	99%	1%	0%
	10 km	1.4E-02	9.7E-02	92%	8%	0%	1.6E+00	99%	1%	0%
	25 km	1.4E-02	9.7E-02	92%	8%	0%	1.6E+00	99%	1%	0%
Large Coal-fired Utility Boiler	2.5 km	3.1E-02	2.1E-01	43%	4%	53%	1.6E+00	99%	1%	0%
	10 km	1.9E-02	1.3E-01	70%	6%	24%	1.6E+00	99%	1%	0%
	25 km	1.8E-02	1.2E-01	73%	6%	21%	1.6E+00	99%	1%	0%
Medium Coal-fired Utility Boiler	2.5 km	2.3E-02	1.5E-01	58%	5%	37%	1.6E+00	99%	1%	0%
	10 km	2.0E-02	1.4E-01	66%	6%	28%	1.6E+00	99%	1%	0%
	25 km	1.8E-02	1.2E-01	74%	6%	19%	1.6E+00	99%	1%	0%
Small Coal-fired Utility Boiler	2.5 km	1.9E-02	1.3E-01	70%	6%	24%	1.6E+00	99%	1%	0%
	10 km	1.6E-02	1.1E-01	81%	7%	13%	1.6E+00	99%	1%	0%
	25 km	1.5E-02	1.0E-01	88%	7%	4%	1.6E+00	99%	1%	0%
Medium OIl-fired Utility Boiler	2.5 km	1.5E-02	1.0E-01	90%	8%	2%	1.6E+00	99%	1%	0%
	10 km	1.5E-02	9.9E-02	91%	8%	2%	1.6E+00	99%	1%	0%
	25 km	1.4E-02	9.8E-02	92%	8%	1%	1.6E+00	99%	1%	0%
Chlor-alkali plant	2.5 km	1.0E+00	6.9E+00	1%	0%	99%	3.7E+00	44%	0%	56%
	10 km	1.2E-01	8.0E-01	11%	1%	88%	1.9E+00	83%	1%	16%
	25 km	3.7E-02	2.5E-01	36%	3%	61%	1.7E+00	93%	1%	6%

Table 2-19
Predicted Mercury Values in Water Column and Biota for Western Site (ISC3 + RELMAP 90th)

90th Percentile											
		MHg Dissolved Water Conc.(ng/l)	**Tier 4 Fish MHg Concentration (ug/g)**	**%Background**	**%Rel Map**	**%ISC**	**Total Hg Grain Concentration (ng/g)**	**%Background**	**%Rel Map**	**%ISC**
Variant b:Large Municipal Waste Combustor	2.5 km	1.1E-01	7.3E-01	12%	19%	68%	1.7E+00	94%	3%	3%
	10 km	7.5E-02	5.1E-01	18%	28%	54%	1.7E+00	95%	3%	2%
	25 km	4.7E-02	3.2E-01	28%	45%	28%	1.7E+00	96%	3%	1%
Variant b:Small Municipal Waste Combustor	2.5 km	5.3E-02	3.6E-01	25%	39%	36%	1.7E+00	96%	3%	1%
	10 km	3.9E-02	2.7E-01	34%	53%	13%	1.7E+00	97%	3%	0%
	25 km	3.5E-02	2.4E-01	37%	59%	4%	1.7E+00	97%	3%	0%
Large Commercial HMI	2.5 km	5.4E-02	3.6E-01	25%	39%	36%	1.7E+00	96%	3%	1%
	10 km	3.6E-02	2.5E-01	36%	58%	6%	1.7E+00	97%	3%	0%
	25 km	3.5E-02	2.4E-01	38%	61%	1%	1.7E+00	97%	3%	0%
Large Hospital HMI	2.5 km	1.6E-01	1.1E+00	8%	13%	79%	1.7E+00	94%	3%	4%
	10 km	5.1E-02	3.5E-01	26%	41%	33%	1.7E+00	96%	3%	1%
	25 km	3.8E-02	2.6E-01	35%	55%	10%	1.7E+00	97%	3%	0%
Small Hospital HMI	2.5 km	4.3E-02	2.9E-01	31%	49%	20%	1.7E+00	97%	3%	0%
	10 km	3.5E-02	2.4E-01	38%	60%	3%	1.7E+00	97%	3%	0%
	25 km	3.4E-02	2.3E-01	38%	61%	1%	1.7E+00	97%	3%	0%
Large Hospital HMI (wet scrubber)	2.5 km	3.8E-02	2.6E-01	35%	55%	10%	1.7E+00	97%	3%	0%
	10 km	3.5E-02	2.3E-01	38%	61%	1%	1.7E+00	97%	3%	0%
	25 km	3.4E-02	2.3E-01	39%	61%	0%	1.7E+00	97%	3%	0%
Small Hospital HMI (wet scrubber)	2.5 km	3.4E-02	2.3E-01	38%	61%	1%	1.7E+00	97%	3%	0%
	10 km	3.4E-02	2.3E-01	39%	61%	0%	1.7E+00	97%	3%	0%
	25 km	3.4E-02	2.3E-01	39%	61%	0%	1.7E+00	97%	3%	0%
Large Coal-fired Utility Boiler	2.5 km	5.0E-02	3.4E-01	26%	42%	32%	1.7E+00	97%	3%	0%
	10 km	3.9E-02	2.6E-01	34%	54%	12%	1.7E+00	97%	3%	0%
	25 km	3.8E-02	2.6E-01	35%	55%	10%	1.7E+00	97%	3%	0%
Medium Coal-fired Utility Boiler	2.5 km	4.3E-02	2.9E-01	31%	49%	20%	1.7E+00	97%	3%	0%
	10 km	4.0E-02	2.7E-01	33%	53%	14%	1.7E+00	97%	3%	0%
	25 km	3.8E-02	2.6E-01	35%	56%	9%	1.7E+00	97%	3%	0%
Small Coal-fired Utility Boiler	2.5 km	3.9E-02	2.6E-01	34%	54%	12%	1.7E+00	97%	3%	0%
	10 km	3.6E-02	2.5E-01	36%	58%	6%	1.7E+00	97%	3%	0%
	25 km	3.5E-02	2.4E-01	38%	60%	2%	1.7E+00	97%	3%	0%
Medium OIl-fired Utility Boiler	2.5 km	3.4E-02	2.3E-01	38%	61%	1%	1.7E+00	97%	3%	0%
	10 km	3.4E-02	2.3E-01	38%	61%	1%	1.7E+00	97%	3%	0%
	25 km	3.4E-02	2.3E-01	38%	61%	0%	1.7E+00	97%	3%	0%
Chlor-alkali plant	2.5 km	1.0E+0	7.1E+00	1%	2%	97%	3.7E+00	43%	1%	55%
	10 km	1.4E-01	9.4E-01	10%	15%	75%	2.0E+00	82%	2%	16%
	25 km	5.7E-02	3.9E-01	23%	37%	40%	1.8E+00	92%	3%	6%

3. PREDICTED INDIVIDUAL EXPOSURE

Using the three models, RELMAP, ISC3, and IEM-2M as well as the hypothetical exposure scenarios described in Chapter 2 of this Volume, estimates of exposure to individuals residing around local emissions sources were developed. This exposure assessment incorperated many variables including types of emissions sources, activity patterns of exposed individuals, climate and impact of regional atmospheric mercury. Different combinations of these variables provide for a number of potential outputs. This chapter initially presents a description of the results for one such combination; this is presented to illustrate how the other combinations presented were developed. This section is followed by a presentation of the results of the modeling.

3.1 Illustration of Exposure Results

The purpose of this section is to illustrate the results of the exposure modeling by discussing the results for one facility, distance and site. For the purpose of illustration, the large hospital HMI without a wet scrubber is selected in the eastern site, and the RELMAP 50th percentile is used as as an example of the contribution of regional anthropogenic mercury sources. It is noted that a complete discussion is not practical for all facilities; there are 144 possible combinations: 12 model plants, 2 sites, 3 distances, and two possible RELMAP values (50th percentile or 90th percentile). These results demonstrate the impacts of the exposure assessment assumptions used for the hypothetical populations inhabiting the watershed and water body. It also provides a forum to discuss the more general features and implications of the exposure assumptions.

The hospital HMI model plant is assumed to emit a total of 24 kg of mercury a year. Of these mercury emissions, 73% is divalent mercury vapor, 25 is divalent mercury attached to particulates, and 2% is elemental mercury vapor. At 2.5 km from the source, the total area-averaged air concentration is predicted to be 1.7 ng/m^3, of which approximately 3% is predicted to be due to the facility and the rest to regional sources addressed with the RELMAP. The total mercury deposition rate on the watershed is predicted to be 44 µg/m^2/yr, with about 70% (30 µg/m^2/yr) due to the facility; the total deposition rate is the sum of the predictions of RELMAP (50th percentile) and ISC3 at 2.5 km from the facility in the prevailing downwind direction. The predicted area-averaged deposition rate onto the waterbody, which is located on the side closest to the facility, is 88 µg/m^2/yr.

The air concentration and deposition rates predicted for the facility are combined with the 50th percentile of the results for the RELMAP model and used as inputs for the IEM-2M model. The initial conditions assumed are the steady-state results after modeling two different periods of constant deposition and air concentration. The first period reflects pre-industrial conditions, in which case a mercury air concentration of 0.5 ng/m^3 and deposition rate of 3 µg/m^2/yr are assumed. The second period represents conditions that exist after the pre-industrial period but before the facility is in operation. The assumed air concentration was 1.6 ng/m^3 and the deposition rate was 10 µg/m^2/yr. Table 3-1 shows some of the media concentrations predicted after these two simulations.

Table 3-1
Predicted Mercury Concentrations after Pre-facility Simulations Performed for Eastern Site
(these results are used as initial conditions in IEM-2M model for this site)

		%Hg0	%Hg2	%MHg
Watershed soil (ng/g)	47	0.02	98	2
Dissolved in water column (ng/L)	0.9	8	85	7

3.1.1 Concentrations in Environmental Media and Biota

The predicted concentrations of the three mercury species considered are summarized for various environmental media and biota in the Table 3-2.

Table 3-2
Modeled results for Large Hospital HMI
(Humid Site, 2.5 km) Using ISC3 + RELMAP (East 50th percentile)

	Total	**%RelMap**	**%ISC**			
Waterbody Deposition Rate (µg/m2/yr)	**8.8E+01**	**16%**	**84%**			
Watershed Air Concentration (ng/m3)	**1.7E+00**	**97%**	**3%**			
Watershed Deposition Rate (µg/m2/yr)	**4.4E+01**	**33%**	**67%**			
		%Relmap	**%Background**	**%ISC**	**%Hg2**	**%MHg**
Total Mercury Dissolved Surface Water Concentration (ng/L)	2.9					
Dissolved Methylmercury concentration in water body (ng/L)	0.19	6%	34%	60%	0%	100%
Tier 3 Fish	3.1E-01	6%	34%	60%	0%	100%
Tier 4 Fish	1.3E+00	6%	34%	60%	0%	100%
Tilled Soil (ng/g)	5.0E+01	1%	93%	6%	98%	2%
Notill soil (ng/g)	1.1E+02	7%	44%	48%	98%	2%
Produce (µg/g dry weight)						
Grain	2.1E-03	3%	93%	4%	92%	8%
Root Uptake	22%					
Direct Deposition	0%					
Air-to-plant	78%					
Legumes	2.5E-03	3%	91%	6%	93%	7%
Root Uptake	31%					
Direct Deposition	3%					
Air-to-plant	66%					
Potatoes	5.1E-03	1%	93%	6%	96%	4%
Root Uptake	100%					
Direct Deposition	0%					

	Total	%RelMap	%ISC			
Waterbody Deposition Rate (µg/m2/yr)	**8.8E+01**	**16%**	**84%**			
Watershed Air Concentration (ng/m3)	**1.7E+00**	**97%**	**3%**			
Watershed Deposition Rate (µg/m2/yr)	**4.4E+01**	**33%**	**67%**			
		%Relmap	**%Background**	**%ISC**	**%Hg2**	**%MHg**
Air-to-plant	0%					

Table 3-2 (continued)
Modeled results for Large Hospital HMI
(Humid Site, 2.5 km) Using ISC3 + RELMAP (East 50th percentile)

	Total	%RelMap	%ISC			
Waterbody Deposition Rate (µg/m2/yr)	**8.8E+01**	**16%**	**84%**			
Watershed Air Concentration (ng/m3)	**1.7E+00**	**97%**	**3%**			
Watershed Deposition Rate (µg/m2/yr)	**4.4E+01**	**33%**	**67%**			
		%Relmap	**%Background**	**%ISC**	**%Hg2**	**%MHg**
Root Vegetables	1.9E-03	1%	93%	6%	95%	5%
Root Uptake	100%					
Direct Deposition	0%					
Air-to-plant	0%					
Fruits	3.5E-02	4%	92%	4%	95%	5%
Root Uptake	3%					
Direct Deposition	1%					
Air-to-plant	96%					
Fruiting Vegetables	3.5E-02	4%	92%	4%	95%	5%
Root Uptake	3%					
Direct Deposition	1%					
Air-to-plant	96%					
Leafy Vegetables	3.4E-02	4%	91%	5%	79%	21%
Root Uptake	0%					
Direct Deposition	2%					
Air-to-plant	98%					
Animal Products (µg/g dry weight)						
Beef	8.6E-03	4%	86%	10%	81%	19%
from grain	0%					
from Forage	71%					
from Silage	20%					
from Soil	9%					
Beef Liver	2.2E-02	4%	86%	10%	81%	19%
from grain	0%					
from Forage	71%					
from Silage	20%					
from Soil	9%					
Dairy	1.1E-02	4%	87%	9%	81%	19%
from grain	1%					
from Forage	70%					
from Silage	21%					
from Soil	8%					
Pork	7.0E-06	4%	89%	7%	82%	18%
from grain	12%					
from Silage	81%					
from Soil	7%					
Poultry	1.2E-04	7%	52%	41%	97%	3%
from grain	15%					
from Soil	85%					
Eggs	1.2E-04	7%	52%	41%	97%	3%
from grain	15%					

Table 3-2 (continued)
Modeled results for Large Hospital HMI
(Humid Site, 2.5 km) Using ISC3 + RELMAP (East 50th percentile)

	Total	%RelMap	%ISC			
Waterbody Deposition Rate (µg/m2/yr)	**8.8E+01**	**16%**	**84%**			
Watershed Air Concentration (ng/m3)	**1.7E+00**	**97%**	**3%**			
Watershed Deposition Rate (µg/m2/yr)	**4.4E+01**	**33%**	**67%**			
		%Relmap	**%Background**	**%ISC**	**%Hg2**	**%MHg**
from Soil	85%					
Lamb	3.9E-03	4%	84%	11%	81%	19%
from forage	88%					
from Soil	12%					
Other Produce (µg/g dry weight)						
Forage	3.5E-02	4%	90%	6%	79%	21%
Root Uptake	0%					
Direct Deposition	4%					
Air-to-plant	96%					
Silage	3.4E-02	4%	92%	4%	79%	21%
Root Uptake	0%					
Direct Deposition	1%					
Air-to-plant	99%					

3.1.1.1 Methylmercury Concentrations in Fish

The methylmercury concentration in the fish is determined by multiplying the dissolved methylmercury concentration in water by a BAF (derivation is described in Volume 3 Appendix D). The facility is predicted to account for more than half of the methylmercury in the fish for the waterbody located 2.5 km from the source. This is not via the deposition of methylmercury itself; rather, it is due to the deposition of elemental and divalent mercury which is either predicted to be methylated after direct deposition in the water body, or is methylated in the watershed soil and subsequently flows into the waterbody via runoff or erosion.

The "background" is predicted to account for approximately one third of the methylmercury concentration in fish. This background represents the steady-state conditions that are predicted to exist prior to both the facility and the sources represented in the RELMAP modeling, and are used as initial conditions in the IEM-2M modeling to predict biota concentrations and human exposure.

In the four-tier trophic food chain model used in this Report, fish were assumed to feed at two levels. Trophic level 3 fish were assumed to feed on plankton which are predicted to be contaminated with comparatively low levels of methylmercury. Trophic level 4 fish were assumed to feed on trophic level 3 fish, which have higher methylmercury concentrations than the plankton. The median BAF of 1.6e6 L/kg for trophic level 3 fish was estimated using several sets of data on measured mercury concentrations in fish and water. The media BAF for trophic level 4 of 6.8e6 L/kg) was estimated by applying a predator-prey factor (of approximately 5) to the bioaccumulation factor estimated for trophic level 3 fish.

3.1.1.2 Concentrations in Other Biota

Plant Concentrations

Three routes by which plants can take up mercury are addressed here: root uptake, whereby the plant is assumed to take up mercury from the soil; direct deposition, whereby the mercury deposited on the plantshoot from atmospheric deposition transfers to the plant; and air-to-plant transfer, whereby the mercury in the air is transported through the stomata into the plant. In all cases, at least 79% of the mercury in the plant products is predicted to be of the divalent form, with the rest being methylmercury.

The mercury in potatoes and root vegetables results solely from root uptake since no air uptake was assumed to occur for these plants (Appendix B of Volume III). For leafy vegetables, all the mercury is predicted to be from air uptake since no root uptake was assumed to occur. For grains, legumes, fruits and fruiting vegetables the bulk of mercury is also modeled to come from air uptake of elemental mercury and transformation to other species; note, however, that the air and soil biotransfer factors were calculated based on a conservative premise that air and soil uptake should be of comparable strength. This was done because the soil concentrations used for this demonstration are several times lower than the soil concentrations from the Cappon (1981 and 1987) studies from which the soil BCFs were derived. For more details pertaining to the plant-soil BCF please see Appendix B of Volume III.

Generally, the facility is predicted to contribute less than 10% to the total mercury plant concentration. For the plant types for which air-uptake is assumed to be the primary source of mercury, the facility contribution is similar to the contribution of the facility to the local air concentrations. For the plant types that uptake mercury primarily from the soil, it is due to the predicted dynamics of the tilled soil in which the plants are assumed to be grown.

Hanson et al. (1994) stated that "dry foliar surfaces in terrestrial forest landscapes may not be a net sink for atmospheric Hg^0, but rather as a dynamic exchange surface that can function as a source or sink dependent on current Hg vapor concentrations, leaf temperatures, surface condition (wet versus dry) and level of atmospheric oxidants." Similarly, Mosbaek et al. (1988) showed that most of the mercury in leafy plants is attributable to air-leaf transfer, but that for a given period of time the amount of elemental mercury released from the plant-soil system greatly exceeds the amount collected from the air by the plants. It is also likely that many plants accumulate airborne mercury to certain concentrations, after which net deposition of elemental mercury does not occur. This is also a function of the large area of uncertainty in deriving soil-to-plant and air-to-plant BCFs for mercury due to the wide variation in values among different studies. This is described in Appendix B of Volume III, Section B.1.2.2, B.1.2.2.1, and B.1.2.2.2.

In general, the plant uptake of mercury is predicted to be dominated by either root uptake or air-to-plant transfer. For facilities in which the deposition rate is significantly higher, direct deposition may be a more important pathway. Similarly, the root uptake pathway may be more important in areas with higher soil concentrations.

3.1.1.3 Mercury Concentrations in Animal Products

The concentrations in animal products were calculated by multiplying the total daily intake of a particular species of mercury by a transfer factor that can depend on the animal species and tissue. The animals considered may be exposed to mercury via four possible pathways: ingestion of contaminated grain, forage, silage, or soil. The contribution from these pathways depends on both the predicted concentration in the plant or soil and the ingestion rate for a particular pathway.

For beef and dairy products, most of the intake of mercury is from forage and silage because these plants are assumed to make up over 80% of their total diet (see Appendix A). The predicted concentration for beef liver is slightly higher than that for beef due to a higher transfer factor for beef liver. For poultry products, most of the mercury exposure is predicted to occur through the ingestion of soil (N.B. the untilled soil is assumed to be consumed).

3.1.2. Results for Hypothetical Exposure Scenarios

In this section the predicted biota concentrations are used in conjunction with the hypothetical exposure scenarios to estimate exposure to the human receptors.

Based on the predicted concentrations in biota and using the hypothetical exposure scenarios described in the previous sections, the predicted human intake rates for each scenario are shown in Tables 3-3 through Table 3-8.

In general, exposure to mercury is dominated by indirect exposure for any scenario that includes an ingestion pathway other than soil. Furthermore, exposure tends to be dominated by either divalent or methylmercury species rather than elemental mercury. For the agricultural and urban scenarios, divalent mercury is the dominant form. For the scenarios that include fish ingestion, methylmercury dominates predicted exposure.

3.1.2.1 Rural Scenarios

For the rural scenarios considered, exposure to divalent mercury accounted for over 90% of the total mercury exposure. The primary exposure pathway is from plant products which account for 50-70% of the total mercury exposure. Most of the exposure through plant products is predicted to occur from consumption of fruits and grains. The rural subsistence farmer receptors are predicted to have about four times as much exposure to mercury as the rural home gardener.

Exposure to mercury from milk (dairy) dominates exposure from animal products for the high end rural scenario considered (total of seven types of animal products are assumed to be consumed). These individuals were assumed not to consume fish; as a consequence, predicted methylmercury exposures are low.

The local source is predicted to account for less than 10% of the total mercury exposure for the rural scenarios.

3.1.2.2 Urban Scenarios

For the urban average scenario, the only exposure pathways considered are inhalation and ingestion of soil. For the urban high end scenario, the ingestion of home grown produce is considered as well, although with lower contact fractions than for the rural home gardener scenario.

For the urban average scenarios, exposure to mercury from the inhalation route was equal to or exceeded indirect exposure. The urban high-end scenario included a small garden to the urban average scenario, with the result that similar contributions to the total divalent mercury and methylmercury exposures occurred as for the rural home gardeners. The urban high-end adult receptor had a predicted mercury exposure of about one-half that of the rural home gardener. The high end urban child scenario consisted of a pica child assumed to ingest 7.5 grams of soil per day. The exposure rate is then proportional to the assumed untilled soil concentration, which in this case is 100 ng/g.

3.1.2.3 Fish Ingestion Scenarios

It was assumed that the high-end fish consumer eats fish from the affected freshwater lake on a daily basis; that is, seasonal consumption rate variation was not addressed. This individual is the most exposed adult to methylmercury in this assessment, and was predicted to be exposed to approximately twice the level of methylmercury that the recreational angler is exposed. Fish consumption is predicted to be the primary source of methylmercury in the diet. The high-end fisher was assumed to consume two times as much fish as the recreational angler (60 g/day vs. 30 g/day). On a gram per bodyweight basis, the high-end fish-consuming child was the maximally exposed subpopulation. This is based on the hypothetical child’s fish consumption rate and the bodyweight, and is consistent with the data presented in the Chapter 4 of this Volume.

For the fish ingestion scenarios, intake of mercury was mainly the methylmercury species. Although intake of methylmercury via plants and soil is considered in the high-end fish consumption scenario, it accounts for less than 1% of the total methylmercury intake. The recreational angler was assumed to be exposed to mercury via fish, soil and water consumption. Exposure via soil and water however, accounted for less than 0.1% of the total mercury intake.

Table 3-3
Predicted Mercury Exposure for Subsistence Farmer Scenario

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)
Subsistence Farmer
mg/kg/day — Adult

	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	4.9E-07		4%	93%	3%	0%	0%
Ingestion Total	4.1E-05	0%	4%	90%	6%	90%	10%
Fish Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Water Ingestion	5.0E-07	1%	25%	56%	18%	97%	2%
Produce Ingestion	2.9E-05	71%	4%	92%	4%	94%	6%
Grains	4.0E-06	10%	3%	93%	4%	92%	8%
Legumes	9.5E-07	2%	3%	91%	6%	93%	7%
Potatoes	8.7E-07	2%	1%	93%	6%	96%	4%
Root vegetables	4.5E-08	0%	1%	93%	6%	95%	5%
Fruits	2.0E-05	49%	4%	92%	4%	95%	5%
Fruiting vegetables	2.2E-06	5%	4%	92%	4%	95%	5%
Leafy vegetables	9.6E-07	2%	4%	91%	5%	79%	21%
Animal Ingestion	1.1E-05	27%	4%	86%	9%	81%	19%
Beef	2.9E-06	7%	4%	86%	10%	81%	19%
Beef liver	1.4E-06	4%	4%	86%	10%	81%	19%
Dairy	6.5E-06	16%	4%	87%	9%	81%	19%
Pork	1.2E-09	0%	4%	89%	7%	82%	18%
Poultry	1.4E-08	0%	7%	52%	41%	97%	3%
Eggs	9.0E-09	0%	7%	52%	41%	97%	3%
Lamb	2.2E-07	1%	4%	84%	11%	81%	19%
Soil Ingestion	1.5E-07	0%	7%	44%	48%	98%	2%

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)
Subsistence Farmer
mg/kg/day — Child

	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	1.6E-06		4%	93%	3%	0%	0%
Total Ingestion	5.3E-05	0%	4%	87%	8%	87%	13%
Fish Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Water Ingestion	1.0E-06	2%	25%	56%	18%	97%	2%
Produce Ingestion	2.3E-05	44%	3%	92%	4%	94%	6%
Grains	8.1E-06	15%	3%	93%	4%	92%	8%
Legumes	1.7E-06	3%	3%	91%	6%	93%	7%
Potatoes	1.4E-06	3%	1%	93%	6%	96%	4%
Root vegetables	6.7E-08	0%	1%	93%	6%	95%	5%
Fruits	7.8E-06	15%	4%	92%	4%	95%	5%
Fruiting vegetables	4.2E-06	8%	4%	92%	4%	95%	5%
Leafy vegetables	2.7E-07	1%	4%	91%	5%	79%	21%
Animal Ingestion	2.8E-05	52%	4%	86%	9%	81%	19%
Beef	4.8E-06	9%	4%	86%	10%	81%	19%
Beef liver	5.4E-07	1%	4%	86%	10%	81%	19%
Dairy	2.2E-05	41%	4%	87%	9%	81%	19%
Pork	1.7E-09	0%	4%	89%	7%	82%	18%
Poultry	2.6E-08	0%	7%	52%	41%	97%	3%
Eggs	1.1E-08	0%	7%	52%	41%	97%	3%
Lamb	2.4E-07	0%	4%	84%	11%	81%	19%
Soil Ingestion	1.2E-06	2%	7%	44%	48%	98%	2%

Table 3-4
Predicted Mercury Exposure for Rural Home Gardener

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)
Rural Home Gardener

mg/kg/day	Adult						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	4.9E-07		4%	93%	3%	0%	0%
Ingestion Total	9.9E-06	0%	4%	91%	5%	94%	6%
Fish Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Water Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Produce Ingestion	9.7E-06	98%	4%	92%	4%	94%	6%
Grains	2.7E-06	27%	3%	93%	4%	92%	8%
Legumes	7.6E-07	8%	3%	91%	6%	93%	7%
Potatoes	2.0E-07	2%	1%	93%	6%	96%	4%
Root vegetables	1.2E-08	0%	1%	93%	6%	95%	5%
Fruits	4.6E-06	47%	4%	92%	4%	95%	5%
Fruiting vegetables	1.4E-06	14%	4%	92%	4%	95%	5%
Leafy vegetables	5.5E-08	1%	4%	91%	5%	79%	21%
Animal Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Beef	0.0E+00	0%	NA	NA	NA	NA	NA
Beef liver	0.0E+00	0%	NA	NA	NA	NA	NA
Dairy	0.0E+00	0%	NA	NA	NA	NA	NA
Pork	0.0E+00	0%	NA	NA	NA	NA	NA
Poultry	0.0E+00	0%	NA	NA	NA	NA	NA
Eggs	0.0E+00	0%	NA	NA	NA	NA	NA
Lamb	0.0E+00	0%	NA	NA	NA	NA	NA
Soil Ingestion	1.5E-07	2%	7%	44%	48%	98%	2%

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)
Rural Home Gardener

mg/kg/day	Child						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	1.6E-06		4%	93%	3%	0%	0%
Total Ingestion	1.3E-05	0%	4%	88%	9%	94%	6%
Fish Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Water Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Produce Ingestion	1.1E-05	90%	3%	92%	4%	94%	6%
Grains	5.4E-06	42%	3%	93%	4%	92%	8%
Legumes	1.3E-06	10%	3%	91%	6%	93%	7%
Potatoes	3.2E-07	2%	1%	93%	6%	96%	4%
Root vegetables	1.8E-08	0%	1%	93%	6%	95%	5%
Fruits	1.8E-06	14%	4%	92%	4%	95%	5%
Fruiting vegetables	2.6E-06	20%	4%	92%	4%	95%	5%
Leafy vegetables	1.6E-08	0%	4%	91%	5%	79%	21%
Animal Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Beef	0.0E+00	0%	NA	NA	NA	NA	NA
Beef liver	0.0E+00	0%	NA	NA	NA	NA	NA
Dairy	0.0E+00	0%	NA	NA	NA	NA	NA
Pork	0.0E+00	0%	NA	NA	NA	NA	NA
Poultry	0.0E+00	0%	NA	NA	NA	NA	NA
Eggs	0.0E+00	0%	NA	NA	NA	NA	NA
Lamb	0.0E+00	0%	NA	NA	NA	NA	NA
Soil Ingestion	1.2E-06	10%	7%	44%	48%	98%	2%

Table 3-5
Predicted Mercury Exposure for Urban Average Scenario

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
Urban Average							
mg/kg/day	Adult						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	3.3E-07		4%	93%	3%	0%	0%
Ingestion Total	2.0E-07	100%	6%	54%	40%	98%	2%
Soil Ingestion	2.0E-07	100%	6%	54%	40%	98%	2%
ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
Urban Average							
mg/kg/day	Child						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	1.6E-06		4%	93%	3%	0%	0%
Total Ingestion	1.6E-06	100%	6%	54%	40%	98%	2%
Soil Ingestion	1.6E-06	100%	6%	54%	40%	98%	2%

Table 3-6
Predicted Mercury Exposure for Urban High-end Scenarios

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
Urban High End							
mg/kg/day	Adult						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	4.9E-07		4%	93%	3%	0%	0%
Ingestion Total	4.0E-06	100%	4%	91%	6%	94%	6%
Fish Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Water Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Produce Ingestion	3.8E-06	95%	3%	93%	4%	94%	6%
Grains	8.8E-07	22%	3%	94%	3%	93%	7%
Legumes	5.6E-07	14%	3%	92%	5%	93%	7%
Potatoes	4.2E-08	1%	1%	95%	4%	96%	4%
Root vegetables	5.1E-09	0%	1%	95%	4%	95%	5%
Fruits	1.5E-06	39%	4%	92%	4%	95%	5%
Fruiting vegetables	7.2E-07	18%	4%	92%	4%	95%	5%
Leafy vegetables	2.5E-08	1%	4%	91%	5%	79%	21%
Soil Ingestion	2.0E-07	5%	6%	54%	40%	98%	2%
ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
Urban High End							
mg/kg/day	Child						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	1.6E-06		4%	93%	3%	0%	0%
Total Ingestion	6.1E-05	100%	6%	54%	40%	98%	2%
Soil Ingestion	6.1E-05	100%	6%	54%	40%	98%	2%

Table 3-7
Predicted Mercury Exposure for High-end Fish Consumption Scenario

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
Subsistence Fisher							
mg/kg/day	Adult						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	4.9E-07		4%	93%	3%	0%	0%
Ingestion Total	1.1E-03	0%	6%	34%	59%	1%	99%
Fish Ingestion	1.1E-03	99%	6%	34%	60%	0%	100%
Water Ingestion	1.0E-07	0%	6%	32%	62%	87%	7%
Produce Ingestion	9.7E-06	1%	4%	92%	4%	94%	6%
Grains	2.7E-06	0%	3%	93%	4%	92%	8%
Legumes	7.6E-07	0%	3%	91%	6%	93%	7%
Potatoes	2.0E-07	0%	1%	93%	6%	96%	4%
Root vegetables	1.2E-08	0%	1%	93%	6%	95%	5%
Fruits	4.6E-06	0%	4%	92%	4%	95%	5%
Fruiting vegetables	1.4E-06	0%	4%	92%	4%	95%	5%
Leafy vegetables	5.5E-08	0%	4%	91%	5%	79%	21%
Animal Ingestion	0.0E+00	0%	NA	NA	NA	NA	NA
Beef	0.0E+00	0%	NA	NA	NA	NA	NA
Beef liver	0.0E+00	0%	NA	NA	NA	NA	NA
Dairy	0.0E+00	0%	NA	NA	NA	NA	NA
Pork	0.0E+00	0%	NA	NA	NA	NA	NA
Poultry	0.0E+00	0%	NA	NA	NA	NA	NA
Eggs	0.0E+00	0%	NA	NA	NA	NA	NA
Lamb	0.0E+00	0%	NA	NA	NA	NA	NA
Soil Ingestion	1.5E-07	0%	7%	44%	48%	98%	2%

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
High end Fish Consumer							
mg/kg/day	Child						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	1.6E-06		4%	93%	3%	0%	0%
Total Ingestion	1.6E-03	0%	6%	34%	59%	1%	99%
Fish Ingestion	1.5E-03	99%	6%	34%	60%	0%	100%
Water Ingestion	2.2E-07	0%	6%	32%	62%	87%	7%
Produce Ingestion	1.1E-05	1%	3%	92%	4%	94%	6%
Grains	5.4E-06	0%	3%	93%	4%	92%	8%
Legumes	1.3E-06	0%	3%	91%	6%	93%	7%
Potatoes	3.2E-07	0%	1%	93%	6%	96%	4%
Root vegetables	1.8E-08	0%	1%	93%	6%	95%	5%
Fruits	1.8E-06	0%	4%	92%	4%	95%	5%
Fruiting vegetables	2.6E-06	0%	4%	92%	4%	95%	5%
Leafy vegetables	1.6E-08	0%	4%	91%	5%	79%	21%
Soil Ingestion	1.2E-06	0%	7%	44%	48%	98%	2%

Table 3-8
Predicted Mercury Exposure for Recreational Angler Scenario

ISC: Large Hospital HMI(Humid Site, 2.5 km) + RELMAP(East 50th percentile)							
Recreational Angler							
mg/kg/day	Adult						
	Total		%Relmap	%Background	%ISC	%Hg2	%MHg
Inhalation	4.9E-07		4%	93%	3%	0%	0%
Ingestion Total	5.6E-04	0%	6%	34%	60%	0%	100%
Fish Ingestion	5.6E-04	100%	6%	34%	60%	0%	100%
Water Ingestion	1.0E-07	0%	6%	32%	62%	87%	7%
Soil Ingestion	1.5E-07	0%	7%	45%	48%	98%	2%

3.2 Results of Combining Local and Regional Models - Predicted Human Exposure

In this section the results are presented for combining the local and regional impacts of anthropogenic sources. For both the eastern and western sites, the 50th and 90th percentile of the predicted air concentrations and deposition rates by the regional air model are used in conjunction with the air concentrations and deposition rates predicted by the local scale model for each plant to obtain estimates of environmental concentrations and possible exposure for humans. Background mercury concentrations in environmental media are also included.

Tables 3-9 through 3-22 show the predicted human intake for each exposure scenario and site. The results include receptors located at three distances from the facility (2.5km, 10km, and 25km). In all cases, the predicted impact of the local source decreases as the distance from the local source increases.

3.2.1 Inhalation

Only for the chlor-alkali plant is the local source predicted to account for more than 50% of total mercury exposure due to inhalation, and then only for the closest receptor considered (2.5km). The primary form of mercury that constitutes this exposure is elemental mercury. Further, the inhalation route is rarely predicted to be the dominant pathway of total mercury exposure when compared to indirect exposure. The exception is the “urban average” exposure, in which an adult is assumed to ingest average amounts of soil in the impacted area. The insignificance of exposure through the inhalation route when compared to ingestion routes was described previously by the WHO (WHO, 1990).

3.2.2 Agricultural Scenarios

In general, the local source is predicted to account for less than 10% of the total mercury exposure for the agricultural scenarios, compared to the contribution of the regional sources (RELMAP) and background. This is because for these scenarios ingestion of plants is the dominant pathway for mercury exposure, and the plant concentrations are predicted to accumulate mercury from the air more than via soil uptake. The contribution of the local source is then roughly equivalent to the impact of the local source on the air concentration. It is only for the chlor-alkali plant that this contribution is more than 20% (at 2.5km and 10km). The mercury in potatoes and root vegetables results solely from root uptake since no air uptake was assumed to occur for these plants (Appendix A). For leafy vegetables, all the mercury is predicted to be from air uptake since no root uptake was assumed to occur. For grains, legumes, fruits and

Table 3-9
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Farmer

Eastern Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Farmer											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	5.4E-05	9%	4.1E-05	6%	5.1E-05	4%	4.0E-05	4%	5.0E-05	2%	3.9E-05	2%
Variant b:Small Municipal Waste Combustor	5.0E-05	2%	3.9E-05	1%	4.9E-05	1%	3.9E-05	1%	4.9E-05	0%	3.8E-05	0%
Large Commercial HMI	5.0E-05	2%	3.9E-05	1%	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Large Hospital HMI	5.3E-05	8%	4.1E-05	6%	5.0E-05	2%	3.9E-05	1%	4.9E-05	1%	3.8E-05	0%
Small Hospital HMI	4.9E-05	1%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Large Hospital HMI (wet scrubber)	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Small Hospital HMI (wet scrubber)	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Large Coal-fired Utility Boiler	5.1E-05	4%	3.9E-05	3%	5.0E-05	1%	3.9E-05	1%	4.9E-05	0%	3.8E-05	0%
Medium Coal-fired Utility Boiler	5.0E-05	2%	3.9E-05	1%	4.9E-05	1%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Small Coal-fired Utility Boiler	4.9E-05	1%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Medium OIl-fired Utility Boiler	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%	4.9E-05	0%	3.8E-05	0%
Chlor-alkali plant	1.3E-04	62%	9.6E-05	60%	6.3E-05	23%	4.9E-05	22%	5.3E-05	8%	4.2E-05	8%

Table 3-9 (continued)
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Farmer

Eastern Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Farmer											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	5.7E-05	8%	4.3E-05	6%	5.4E-05	4%	4.2E-05	3%	5.3E-05	2%	4.1E-05	2%
Variant b:Small Municipal Waste Combustor	5.3E-05	2%	4.1E-05	1%	5.3E-05	1%	4.0E-05	1%	5.2E-05	0%	4.0E-05	0%
Large Commercial HMI	5.3E-05	2%	4.1E-05	1%	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Large Hospital HMI	5.7E-05	8%	4.3E-05	6%	5.3E-05	2%	4.1E-05	1%	5.2E-05	0%	4.0E-05	0%
Small Hospital HMI	5.3E-05	1%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Large Hospital HMI (wet scrubber)	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Small Hospital HMI (wet scrubber)	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Large Coal-fired Utility Boiler	5.4E-05	4%	4.1E-05	2%	5.3E-05	1%	4.0E-05	1%	5.2E-05	0%	4.0E-05	0%
Medium Coal-fired Utility Boiler	5.3E-05	2%	4.1E-05	1%	5.2E-05	1%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Small Coal-fired Utility Boiler	5.2E-05	1%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Medium OIl-fired Utility Boiler	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%	5.2E-05	0%	4.0E-05	0%
Chlor-alkali plant	1.3E-04	61%	9.8E-05	59%	6.7E-05	22%	5.1E-05	21%	5.7E-05	8%	4.3E-05	8%

Table 3-10
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Rural Home Gardner

Eastern Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Rural Home Gardener											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.3E-05	8%	9.9E-06	5%	1.2E-05	4%	9.7E-06	3%	1.2E-05	2%	9.5E-06	1%
Variant b:Small Municipal Waste Combustor	1.2E-05	2%	9.5E-06	1%	1.2E-05	1%	9.4E-06	1%	1.2E-05	0%	9.4E-06	0%
Large Commercial HMI	1.2E-05	2%	9.5E-06	1%	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Large Hospital HMI	1.3E-05	9%	9.9E-06	5%	1.2E-05	2%	9.5E-06	1%	1.2E-05	1%	9.4E-06	0%
Small Hospital HMI	1.2E-05	1%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Large Hospital HMI (wet scrubber)	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Small Hospital HMI (wet scrubber)	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Large Coal-fired Utility Boiler	1.2E-05	3%	9.5E-06	1%	1.2E-05	1%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Medium Coal-fired Utility Boiler	1.2E-05	2%	9.5E-06	1%	1.2E-05	1%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Small Coal-fired Utility Boiler	1.2E-05	1%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Medium OIl-fired Utility Boiler	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%	1.2E-05	0%	9.4E-06	0%
Chlor-alkali plant	3.0E-05	62%	2.2E-05	58%	1.5E-05	22%	1.2E-05	20%	1.3E-05	8%	1.0E-05	7%

Table 3-10 (continued)
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Rural Home Gardner

Eastern Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Rural Home Gardener											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.3E-05	8%	1.0E-05	5%	1.3E-05	4%	1.0E-05	3%	1.2E-05	2%	9.9E-06	1%
Variant b:Small Municipal Waste Combustor	1.2E-05	2%	9.8E-06	1%	1.2E-05	1%	9.8E-06	1%	1.2E-05	0%	9.8E-06	0%
Large Commercial HMI	1.2E-05	2%	9.8E-06	1%	1.2E-05	0%	9.8E-06	0%	1.2E-05	0%	9.7E-06	0%
Large Hospital HMI	1.3E-05	8%	1.0E-05	5%	1.2E-05	2%	9.8E-06	1%	1.2E-05	1%	9.8E-06	0%
Small Hospital HMI	1.2E-05	1%	9.8E-06	0%	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%
Large Hospital HMI (wet scrubber)	1.2E-05	0%	9.8E-06	0%	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%
Small Hospital HMI (wet scrubber)	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%
Large Coal-fired Utility Boiler	1.3E-05	3%	9.8E-06	1%	1.2E-05	1%	9.8E-06	0%	1.2E-05	0%	9.7E-06	0%
Medium Coal-fired Utility Boiler	1.2E-05	2%	9.8E-06	1%	1.2E-05	1%	9.8E-06	0%	1.2E-05	0%	9.7E-06	0%
Small Coal-fired Utility Boiler	1.2E-05	0%	9.8E-06	0%	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%
Medium OIl-fired Utility Boiler	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%	1.2E-05	0%	9.7E-06	0%
Chlor-alkali plant	3.1E-05	60%	2.3E-05	57%	1.6E-05	21%	1.2E-05	20%	1.3E-05	7%	1.0E-05	7%

Table 3-11
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban Average

Eastern Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Urban Average											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.6E-06	38%	1.9E-07	38%	1.2E-06	20%	1.5E-07	20%	1.1E-06	8%	1.3E-07	8%
Variant b:Small Municipal Waste Combustor	1.1E-06	10%	1.3E-07	10%	1.0E-06	3%	1.2E-07	3%	1.0E-06	1%	1.2E-07	1%
Large Commercial HMI	1.1E-06	9%	1.3E-07	9%	1.0E-06	2%	1.2E-07	2%	1.0E-06	0%	1.2E-07	0%
Large Hospital HMI	1.6E-06	40%	2.0E-07	40%	1.1E-06	10%	1.3E-07	10%	1.0E-06	3%	1.2E-07	3%
Small Hospital HMI	1.0E-06	4%	1.3E-07	4%	1.0E-06	1%	1.2E-07	1%	9.9E-07	0%	1.2E-07	0%
Large Hospital HMI (wet scrubber)	1.0E-06	2%	1.2E-07	2%	1.0E-06	0%	1.2E-07	0%	9.9E-07	0%	1.2E-07	0%
Small Hospital HMI (wet scrubber)	9.9E-07	0%	1.2E-07	0%	9.9E-07	0%	1.2E-07	0%	9.9E-07	0%	1.2E-07	0%
Large Coal-fired Utility Boiler	1.3E-06	26%	1.6E-07	26%	1.1E-06	6%	1.3E-07	6%	1.0E-06	2%	1.2E-07	2%
Medium Coal-fired Utility Boiler	1.1E-06	13%	1.4E-07	13%	1.0E-06	4%	1.3E-07	4%	1.0E-06	2%	1.2E-07	2%
Small Coal-fired Utility Boiler	1.0E-06	3%	1.2E-07	3%	1.0E-06	1%	1.2E-07	1%	1.0E-06	0%	1.2E-07	0%
Medium OIl-fired Utility Boiler	1.0E-06	0%	1.2E-07	0%	9.9E-07	0%	1.2E-07	0%	9.9E-07	0%	1.2E-07	0%
Chlor-alkali plant	6.1E-06	84%	7.4E-07	84%	1.7E-06	41%	2.0E-07	41%	1.2E-06	15%	1.4E-07	15%

Table 3-11 (continued)
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban Average

Eastern Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Urban Average											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.9E-06	32%	2.3E-07	32%	1.5E-06	16%	1.8E-07	16%	1.4E-06	7%	1.7E-07	7%
Variant b:Small Municipal Waste Combustor	1.4E-06	8%	1.7E-07	8%	1.3E-06	3%	1.6E-07	3%	1.3E-06	1%	1.6E-07	1%
Large Commercial HMI	1.4E-06	7%	1.7E-07	7%	1.3E-06	1%	1.6E-07	1%	1.3E-06	0%	1.5E-07	0%
Large Hospital HMI	1.9E-06	34%	2.3E-07	34%	1.4E-06	8%	1.7E-07	8%	1.3E-06	2%	1.6E-07	2%
Small Hospital HMI	1.3E-06	3%	1.6E-07	3%	1.3E-06	0%	1.6E-07	0%	1.3E-06	0%	1.5E-07	0%
Large Hospital HMI (wet scrubber)	1.3E-06	1%	1.6E-07	1%	1.3E-06	0%	1.5E-07	0%	1.3E-06	0%	1.5E-07	0%
Small Hospital HMI (wet scrubber)	1.3E-06	0%	1.5E-07	0%	1.3E-06	0%	1.5E-07	0%	1.3E-06	0%	1.5E-07	0%
Large Coal-fired Utility Boiler	1.6E-06	21%	2.0E-07	21%	1.3E-06	5%	1.6E-07	5%	1.3E-06	2%	1.6E-07	2%
Medium Coal-fired Utility Boiler	1.4E-06	10%	1.7E-07	10%	1.3E-06	3%	1.6E-07	3%	1.3E-06	1%	1.6E-07	1%
Small Coal-fired Utility Boiler	1.3E-06	3%	1.6E-07	3%	1.3E-06	1%	1.6E-07	1%	1.3E-06	0%	1.5E-07	0%
Medium OIl-fired Utility Boiler	1.3E-06	0%	1.5E-07	0%	1.3E-06	0%	1.5E-07	0%	1.3E-06	0%	1.5E-07	0%
Chlor-alkali plant	6.4E-06	80%	7.7E-07	80%	2.0E-06	35%	2.4E-07	35%	1.4E-06	12%	1.8E-07	12%

Table 3-12
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban High End

Eastern Site

RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Urban High End											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	5.9E-05	38%	3.9E-06	6%	4.6E-05	20%	3.9E-06	3%	4.0E-05	8%	3.8E-06	2%
Variant b:Small Municipal Waste Combustor	4.1E-05	10%	3.8E-06	1%	3.8E-05	3%	3.7E-06	1%	3.7E-05	1%	3.7E-06	0%
Large Commercial HMI	4.0E-05	9%	3.8E-06	1%	3.7E-05	2%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%
Large Hospital HMI	6.1E-05	40%	4.0E-06	6%	4.1E-05	10%	3.8E-06	1%	3.8E-05	3%	3.7E-06	0%
Small Hospital HMI	3.8E-05	4%	3.7E-06	0%	3.7E-05	1%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%
Large Hospital HMI (wet scrubber)	3.7E-05	2%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%
Small Hospital HMI (wet scrubber)	3.7E-05	0%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%
Large Coal-fired Utility Boiler	4.9E-05	26%	3.8E-06	2%	3.9E-05	6%	3.7E-06	0%	3.8E-05	2%	3.7E-06	0%
Medium Coal-fired Utility Boiler	4.2E-05	13%	3.8E-06	1%	3.8E-05	4%	3.7E-06	0%	3.7E-05	2%	3.7E-06	0%
Small Coal-fired Utility Boiler	3.8E-05	3%	3.7E-06	0%	3.7E-05	1%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%
Medium OIl-fired Utility Boiler	3.7E-05	0%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%	3.7E-05	0%	3.7E-06	0%
Chlor-alkali plant	2.3E-04	84%	8.9E-06	58%	6.2E-05	41%	4.7E-06	20%	4.3E-05	15%	4.0E-06	7%

Table 3-12 (continued)
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban High End

Eastern Site RELMAP 90th percentile	Predicted Ingestion (mg/kg/day) for Urban High End											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	7.0E-05	33%	4.1E-06	5%	5.6E-05	16%	4.0E-06	3%	5.0E-05	7%	3.9E-06	2%
Variant b:Small Municipal Waste Combustor	5.1E-05	8%	3.9E-06	1%	4.8E-05	3%	3.9E-06	1%	4.7E-05	1%	3.9E-06	0%
Large Commercial HMI	5.1E-05	7%	3.9E-06	1%	4.8E-05	1%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%
Large Hospital HMI	7.1E-05	34%	4.1E-06	6%	5.1E-05	8%	3.9E-06	1%	4.8E-05	2%	3.9E-06	0%
Small Hospital HMI	4.9E-05	3%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%
Large Hospital HMI (wet scrubber)	4.8E-05	1%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%
Small Hospital HMI (wet scrubber)	4.7E-05	0%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%
Large Coal-fired Utility Boiler	6.0E-05	21%	3.9E-06	2%	4.9E-05	5%	3.9E-06	0%	4.8E-05	2%	3.9E-06	0%
Medium Coal-fired Utility Boiler	5.3E-05	11%	3.9E-06	1%	4.9E-05	3%	3.9E-06	0%	4.8E-05	1%	3.9E-06	0%
Small Coal-fired Utility Boiler	4.8E-05	3%	3.9E-06	0%	4.8E-05	1%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%
Medium OIl-fired Utility Boiler	4.7E-05	0%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%	4.7E-05	0%	3.9E-06	0%
Chlor-alkali plant	2.4E-04	80%	9.1E-06	57%	7.3E-05	35%	4.8E-06	20%	5.4E-05	12%	4.2E-06	7%

Table 3-13
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Fisher

Eastern Site

RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Fisher											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.4E-03	54%	1.0E-03	54%	9.0E-04	30%	6.6E-04	30%	7.2E-04	13%	5.3E-04	13%
Variant b:Small Municipal Waste Combustor	7.7E-04	18%	5.6E-04	18%	6.7E-04	6%	4.9E-04	6%	6.4E-04	2%	4.7E-04	2%
Large Commercial HMI	7.8E-04	19%	5.7E-04	19%	6.5E-04	3%	4.7E-04	3%	6.3E-04	1%	4.6E-04	1%
Large Hospital HMI	1.6E-03	59%	1.1E-03	59%	7.6E-04	17%	5.6E-04	17%	6.6E-04	4%	4.8E-04	4%
Small Hospital HMI	6.9E-04	9%	5.1E-04	9%	6.4E-04	1%	4.7E-04	1%	6.3E-04	0%	4.6E-04	0%
Large Hospital HMI (wet scrubber)	6.6E-04	4%	4.8E-04	4%	6.3E-04	1%	4.6E-04	1%	6.3E-04	0%	4.6E-04	0%
Small Hospital HMI (wet scrubber)	6.3E-04	0%	4.6E-04	0%	6.3E-04	0%	4.6E-04	0%	6.3E-04	0%	4.6E-04	0%
Large Coal-fired Utility Boiler	1.1E-03	42%	7.9E-04	42%	7.0E-04	10%	5.1E-04	10%	6.5E-04	4%	4.8E-04	4%
Medium Coal-fired Utility Boiler	8.2E-04	23%	6.0E-04	23%	6.7E-04	7%	4.9E-04	7%	6.5E-04	3%	4.7E-04	3%
Small Coal-fired Utility Boiler	6.7E-04	6%	4.9E-04	6%	6.5E-04	2%	4.7E-04	2%	6.3E-04	1%	4.6E-04	1%
Medium OIl-fired Utility Boiler	6.4E-04	1%	4.6E-04	1%	6.3E-04	0%	4.6E-04	0%	6.3E-04	0%	4.6E-04	0%
Chlor-alkali plant	8.0E-03	92%	5.9E-03	92%	1.4E-03	56%	1.0E-03	56%	8.2E-04	23%	5.9E-04	23%

Table 3-13 (continued)
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Fisher

Eastern Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Fisher											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.6E-03	45%	1.2E-03	45%	1.2E-03	23%	8.6E-04	23%	1.0E-03	9%	7.3E-04	9%
Variant b:Small Municipal Waste Combustor	1.1E-03	13%	7.7E-04	13%	9.5E-04	4%	6.9E-04	4%	9.2E-04	1%	6.7E-04	1%
Large Commercial HMI	1.1E-03	14%	7.7E-04	14%	9.3E-04	2%	6.8E-04	2%	9.1E-04	0%	6.7E-04	0%
Large Hospital HMI	1.8E-03	50%	1.3E-03	50%	1.0E-03	13%	7.6E-04	13%	9.4E-04	3%	6.9E-04	3%
Small Hospital HMI	9.7E-04	6%	7.1E-04	6%	9.2E-04	1%	6.7E-04	1%	9.1E-04	0%	6.7E-04	0%
Large Hospital HMI (wet scrubber)	9.4E-04	3%	6.8E-04	3%	9.1E-04	0%	6.7E-04	0%	9.1E-04	0%	6.6E-04	0%
Small Hospital HMI (wet scrubber)	9.1E-04	0%	6.7E-04	0%	9.1E-04	0%	6.6E-04	0%	9.1E-04	0%	6.6E-04	0%
Large Coal-fired Utility Boiler	1.4E-03	33%	1.0E-03	33%	9.8E-04	7%	7.2E-04	7%	9.3E-04	3%	6.8E-04	3%
Medium Coal-fired Utility Boiler	1.1E-03	17%	8.0E-04	17%	9.5E-04	5%	7.0E-04	5%	9.3E-04	2%	6.8E-04	2%
Small Coal-fired Utility Boiler	9.5E-04	4%	7.0E-04	4%	9.3E-04	2%	6.7E-04	2%	9.1E-04	1%	6.7E-04	1%
Medium OIl-fired Utility Boiler	9.2E-04	1%	6.7E-04	1%	9.1E-04	0%	6.7E-04	0%	9.1E-04	0%	6.6E-04	0%
Chlor-alkali plant	8.3E-03	89%	6.1E-03	89%	1.7E-03	47%	1.3E-03	47%	1.1E-03	17%	8.0E-04	17%

Table 3-14
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Recreational Angler

Eastern Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Recreational Angler											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor			5.0E-04	54%			3.3E-04	30%			2.6E-04	13%
Variant b:Small Municipal Waste Combustor			2.8E-04	18%			2.4E-04	6%			2.3E-04	2%
Large Commercial HMI			2.8E-04	19%			2.3E-04	3%			2.3E-04	1%
Large Hospital HMI			5.6E-04	60%			2.8E-04	18%			2.4E-04	5%
Small Hospital HMI			2.5E-04	9%			2.3E-04	1%			2.3E-04	0%
Large Hospital HMI (wet scrubber)			2.4E-04	4%			2.3E-04	1%			2.3E-04	0%
Small Hospital HMI (wet scrubber)			2.3E-04	0%			2.3E-04	0%			2.3E-04	0%
Large Coal-fired Utility Boiler			3.9E-04	42%			2.5E-04	10%			2.4E-04	4%
Medium Coal-fired Utility Boiler			3.0E-04	24%			2.4E-04	7%			2.3E-04	3%
Small Coal-fired Utility Boiler			2.4E-04	6%			2.3E-04	2%			2.3E-04	1%
Medium OIl-fired Utility Boiler			2.3E-04	1%			2.3E-04	0%			2.3E-04	0%
Chlor-alkali plant			2.9E-03	92%			5.2E-04	56%			2.9E-04	23%

Eastern Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Recreational Angler											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor			6.0E-04	45%			4.3E-04	23%			3.6E-04	9%
Variant b:Small Municipal Waste Combustor			3.8E-04	13%			3.4E-04	4%			3.3E-04	1%
Large Commercial HMI			3.8E-04	14%			3.4E-04	2%			3.3E-04	0%
Large Hospital HMI			6.7E-04	51%			3.8E-04	13%			3.4E-04	3%
Small Hospital HMI			3.5E-04	7%			3.3E-04	1%			3.3E-04	0%
Large Hospital HMI (wet scrubber)			3.4E-04	3%			3.3E-04	0%			3.3E-04	0%
Small Hospital HMI (wet scrubber)			3.3E-04	0%			3.3E-04	0%			3.3E-04	0%
Large Coal-fired Utility Boiler			4.9E-04	33%			3.6E-04	7%			3.4E-04	3%
Medium Coal-fired Utility Boiler			4.0E-04	18%			3.5E-04	5%			3.4E-04	2%
Small Coal-fired Utility Boiler			3.4E-04	5%			3.3E-04	2%			3.3E-04	1%
Medium OIl-fired Utility Boiler			3.3E-04	1%			3.3E-04	0%			3.3E-04	0%
Chlor-alkali plant			3.0E-03	89%			6.2E-04	47%			4.0E-04	17%

Table 3-15
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Farmer

Western Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Farmer											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	4.6E-05	8%	3.6E-05	6%	4.4E-05	4%	3.5E-05	3%	4.3E-05	2%	3.5E-05	1%
Variant b:Small Municipal Waste Combustor	4.3E-05	2%	3.5E-05	1%	4.3E-05	1%	3.5E-05	0%	4.3E-05	0%	3.4E-05	0%
Large Commercial HMI	4.3E-05	2%	3.5E-05	1%	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%
Large Hospital HMI	4.6E-05	8%	3.6E-05	5%	4.3E-05	1%	3.5E-05	1%	4.3E-05	0%	3.4E-05	0%
Small Hospital HMI	4.3E-05	1%	3.5E-05	0%	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%
Large Hospital HMI (wet scrubber)	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%
Small Hospital HMI (wet scrubber)	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%
Large Coal-fired Utility Boiler	4.4E-05	3%	3.5E-05	2%	4.3E-05	1%	3.5E-05	0%	4.3E-05	0%	3.4E-05	0%
Medium Coal-fired Utility Boiler	4.3E-05	1%	3.5E-05	1%	4.3E-05	1%	3.5E-05	0%	4.3E-05	0%	3.4E-05	0%
Small Coal-fired Utility Boiler	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%
Medium OIl-fired Utility Boiler	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%	4.3E-05	0%	3.4E-05	0%
Chlor-alkali plant	1.1E-04	61%	8.3E-05	58%	5.2E-05	19%	4.2E-05	17%	4.6E-05	7%	3.7E-05	6%

Table 3-15 (continued)
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Farmer

Western Site												
RELMAP 90th percentile												
	Predicted Ingestion (mg/kg/day) for Subsistence Farmer											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	4.9E-05	7%	3.8E-05	5%	4.7E-05	4%	3.7E-05	3%	4.6E-05	2%	3.6E-05	1%
Variant b:Small Municipal Waste Combustor	4.6E-05	2%	3.6E-05	1%	4.5E-05	1%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Large Commercial HMI	4.6E-05	2%	3.6E-05	1%	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Large Hospital HMI	4.9E-05	7%	3.8E-05	5%	4.6E-05	1%	3.6E-05	1%	4.5E-05	0%	3.6E-05	0%
Small Hospital HMI	4.5E-05	1%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Large Hospital HMI (wet scrubber)	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Small Hospital HMI (wet scrubber)	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Large Coal-fired Utility Boiler	4.6E-05	3%	3.6E-05	2%	4.6E-05	1%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Medium Coal-fired Utility Boiler	4.6E-05	1%	3.6E-05	1%	4.5E-05	1%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Small Coal-fired Utility Boiler	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Medium OIl-fired Utility Boiler	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%	4.5E-05	0%	3.6E-05	0%
Chlor-alkali plant	1.1E-04	60%	8.4E-05	57%	5.5E-05	18%	4.3E-05	17%	4.8E-05	6%	3.8E-05	6%

Table 3-16
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Rural Home Gardner

Western Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Rural Home Gardener 2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	9.9E-06	7%	8.4E-06	4%	9.6E-06	4%	8.3E-06	2%	9.3E-06	2%	8.2E-06	1%
Variant b:Small Municipal Waste Combustor	9.3E-06	2%	8.2E-06	1%	9.2E-06	1%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Large Commercial HMI	9.3E-06	2%	8.2E-06	1%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Large Hospital HMI	1.0E-05	8%	8.5E-06	4%	9.3E-06	2%	8.2E-06	1%	9.2E-06	0%	8.1E-06	0%
Small Hospital HMI	9.2E-06	1%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Large Hospital HMI (wet scrubber)	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Small Hospital HMI (wet scrubber)	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Large Coal-fired Utility Boiler	9.3E-06	1%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Medium Coal-fired Utility Boiler	9.2E-06	1%	8.1E-06	0%	9.2E-06	1%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Small Coal-fired Utility Boiler	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Medium OIl-fired Utility Boiler	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%	9.2E-06	0%	8.1E-06	0%
Chlor-alkali plant	2.5E-05	63%	1.9E-05	57%	1.1E-05	20%	9.8E-06	17%	9.9E-06	7%	8.6E-06	6%

Table 3-16 (continued)
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Rural Home Gardner

Western Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Rural Home Gardener 2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.0E-05	7%	8.6E-06	4%	9.8E-06	4%	8.5E-06	2%	9.6E-06	2%	8.4E-06	1%
Variant b:Small Municipal Waste Combustor	9.6E-06	2%	8.4E-06	1%	9.5E-06	1%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Large Commercial HMI	9.6E-06	2%	8.4E-06	1%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Large Hospital HMI	1.0E-05	8%	8.6E-06	4%	9.6E-06	2%	8.3E-06	1%	9.5E-06	0%	8.3E-06	0%
Small Hospital HMI	9.5E-06	1%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Large Hospital HMI (wet scrubber)	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Small Hospital HMI (wet scrubber)	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Large Coal-fired Utility Boiler	9.6E-06	1%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Medium Coal-fired Utility Boiler	9.5E-06	1%	8.3E-06	0%	9.5E-06	1%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Small Coal-fired Utility Boiler	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Medium OIl-fired Utility Boiler	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%	9.5E-06	0%	8.3E-06	0%
Chlor-alkali plant	2.5E-05	62%	1.9E-05	57%	1.2E-05	19%	9.9E-06	17%	1.0E-05	7%	8.8E-06	6%

Table 3-17
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban Average

Western Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Urban Average											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	4.9E-07	75%	6.0E-08	75%	3.1E-07	60%	3.7E-08	60%	1.9E-07	35%	2.3E-08	35%
Variant b:Small Municipal Waste Combustor	2.0E-07	39%	2.5E-08	39%	1.5E-07	15%	1.8E-08	15%	1.3E-07	5%	1.6E-08	5%
Large Commercial HMI	2.0E-07	38%	2.4E-08	38%	1.3E-07	7%	1.6E-08	7%	1.3E-07	2%	1.5E-08	2%
Large Hospital HMI	6.2E-07	80%	7.5E-08	80%	2.0E-07	38%	2.4E-08	38%	1.4E-07	13%	1.7E-08	13%
Small Hospital HMI	1.6E-07	21%	1.9E-08	21%	1.3E-07	3%	1.5E-08	3%	1.2E-07	1%	1.5E-08	1%
Large Hospital HMI (wet scrubber)	1.4E-07	10%	1.7E-08	10%	1.2E-07	1%	1.5E-08	1%	1.2E-07	0%	1.5E-08	0%
Small Hospital HMI (wet scrubber)	1.2E-07	1%	1.5E-08	1%	1.2E-07	0%	1.5E-08	0%	1.2E-07	0%	1.5E-08	0%
Large Coal-fired Utility Boiler	2.0E-07	37%	2.4E-08	37%	1.5E-07	16%	1.8E-08	16%	1.4E-07	14%	1.7E-08	14%
Medium Coal-fired Utility Boiler	1.6E-07	25%	2.0E-08	25%	1.5E-07	19%	1.8E-08	19%	1.4E-07	13%	1.7E-08	13%
Small Coal-fired Utility Boiler	1.4E-07	15%	1.8E-08	15%	1.3E-07	7%	1.6E-08	7%	1.3E-07	3%	1.5E-08	3%
Medium OIl-fired Utility Boiler	1.3E-07	2%	1.5E-08	2%	1.2E-07	1%	1.5E-08	1%	1.2E-07	0%	1.5E-08	0%
Chlor-alkali plant	4.0E-06	97%	4.9E-07	97%	5.8E-07	79%	7.0E-08	79%	2.4E-07	49%	2.9E-08	49%

Table 3-17 (continued)
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban Average

Western Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Urban Average											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	6.1E-07	61%	7.4E-08	61%	4.2E-07	44%	5.2E-08	44%	3.1E-07	22%	3.7E-08	22%
Variant b:Small Municipal Waste Combustor	3.2E-07	25%	3.9E-08	25%	2.6E-07	9%	3.2E-08	9%	2.5E-07	3%	3.0E-08	3%
Large Commercial HMI	3.2E-07	24%	3.8E-08	24%	2.5E-07	4%	3.0E-08	4%	2.4E-07	1%	2.9E-08	1%
Large Hospital HMI	7.4E-07	67%	8.9E-08	67%	3.1E-07	24%	3.8E-08	24%	2.6E-07	7%	3.1E-08	7%
Small Hospital HMI	2.7E-07	12%	3.3E-08	12%	2.4E-07	2%	3.0E-08	2%	2.4E-07	0%	2.9E-08	0%
Large Hospital HMI (wet scrubber)	2.5E-07	6%	3.1E-08	6%	2.4E-07	1%	2.9E-08	1%	2.4E-07	0%	2.9E-08	0%
Small Hospital HMI (wet scrubber)	2.4E-07	0%	2.9E-08	0%	2.4E-07	0%	2.9E-08	0%	2.4E-07	0%	2.9E-08	0%
Large Coal-fired Utility Boiler	3.1E-07	23%	3.8E-08	23%	2.6E-07	9%	3.2E-08	9%	2.6E-07	8%	3.2E-08	8%
Medium Coal-fired Utility Boiler	2.8E-07	15%	3.4E-08	15%	2.7E-07	10%	3.2E-08	10%	2.6E-07	7%	3.1E-08	7%
Small Coal-fired Utility Boiler	2.6E-07	8%	3.2E-08	8%	2.5E-07	4%	3.0E-08	4%	2.4E-07	1%	2.9E-08	1%
Medium OIl-fired Utility Boiler	2.4E-07	1%	2.9E-08	1%	2.4E-07	1%	2.9E-08	1%	2.4E-07	0%	2.9E-08	0%
Chlor-alkali plant	4.1E-06	94%	5.0E-07	94%	7.0E-07	66%	8.5E-08	66%	3.6E-07	33%	4.4E-08	33%

Table 3-18
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban High End

Western Site

RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Urban High End											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.8E-05	76%	3.1E-06	5%	1.1E-05	61%	3.1E-06	3%	6.9E-06	36%	3.0E-06	1%
Variant b:Small Municipal Waste Combustor	7.3E-06	40%	3.0E-06	1%	5.2E-06	16%	3.0E-06	0%	4.7E-06	6%	3.0E-06	0%
Large Commercial HMI	7.2E-06	39%	3.0E-06	1%	4.8E-06	8%	3.0E-06	0%	4.5E-06	2%	3.0E-06	0%
Large Hospital HMI	2.3E-05	81%	3.2E-06	6%	7.2E-06	38%	3.0E-06	1%	5.1E-06	14%	3.0E-06	0%
Small Hospital HMI	5.6E-06	22%	3.0E-06	0%	4.6E-06	3%	3.0E-06	0%	4.4E-06	1%	3.0E-06	0%
Large Hospital HMI (wet scrubber)	4.9E-06	11%	3.0E-06	0%	4.5E-06	2%	3.0E-06	0%	4.4E-06	0%	3.0E-06	0%
Small Hospital HMI (wet scrubber)	4.4E-06	1%	3.0E-06	0%	4.4E-06	0%	3.0E-06	0%	4.4E-06	0%	3.0E-06	0%
Large Coal-fired Utility Boiler	7.1E-06	38%	3.0E-06	1%	5.3E-06	16%	3.0E-06	0%	5.2E-06	15%	3.0E-06	0%
Medium Coal-fired Utility Boiler	6.0E-06	26%	3.0E-06	0%	5.4E-06	19%	3.0E-06	0%	5.1E-06	13%	3.0E-06	0%
Small Coal-fired Utility Boiler	5.2E-06	15%	3.0E-06	0%	4.8E-06	7%	3.0E-06	0%	4.5E-06	3%	3.0E-06	0%
Medium OIl-fired Utility Boiler	4.5E-06	2%	3.0E-06	0%	4.5E-06	1%	3.0E-06	0%	4.4E-06	0%	3.0E-06	0%
Chlor-alkali plant	1.5E-04	97%	7.3E-06	59%	2.1E-05	79%	3.6E-06	18%	8.8E-06	50%	3.2E-06	6%

Table 3-18 (continued)
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Urban High End

Western Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Urban High End											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	2.3E-05	61%	3.2E-06	5%	1.6E-05	44%	3.1E-06	3%	1.1E-05	22%	3.1E-06	1%
Variant b:Small Municipal Waste Combustor	1.2E-05	25%	3.1E-06	1%	9.6E-06	9%	3.1E-06	0%	9.0E-06	3%	3.1E-06	0%
Large Commercial HMI	1.2E-05	24%	3.1E-06	1%	9.1E-06	4%	3.1E-06	0%	8.8E-06	1%	3.1E-06	0%
Large Hospital HMI	2.7E-05	68%	3.2E-06	6%	1.1E-05	24%	3.1E-06	1%	9.4E-06	8%	3.1E-06	0%
Small Hospital HMI	9.9E-06	12%	3.1E-06	0%	8.9E-06	2%	3.1E-06	0%	8.8E-06	0%	3.1E-06	0%
Large Hospital HMI (wet scrubber)	9.3E-06	6%	3.1E-06	0%	8.8E-06	1%	3.1E-06	0%	8.7E-06	0%	3.1E-06	0%
Small Hospital HMI (wet scrubber)	8.8E-06	0%	3.1E-06	0%	8.7E-06	0%	3.1E-06	0%	8.7E-06	0%	3.1E-06	0%
Large Coal-fired Utility Boiler	1.1E-05	23%	3.1E-06	1%	9.6E-06	9%	3.1E-06	0%	9.5E-06	8%	3.1E-06	0%
Medium Coal-fired Utility Boiler	1.0E-05	15%	3.1E-06	0%	9.8E-06	11%	3.1E-06	0%	9.4E-06	7%	3.1E-06	0%
Small Coal-fired Utility Boiler	9.5E-06	8%	3.1E-06	0%	9.1E-06	4%	3.1E-06	0%	8.8E-06	1%	3.1E-06	0%
Medium OIl-fired Utility Boiler	8.8E-06	1%	3.1E-06	0%	8.8E-06	1%	3.1E-06	0%	8.7E-06	0%	3.1E-06	0%
Chlor-alkali plant	1.5E-04	94%	7.4E-06	58%	2.6E-05	66%	3.7E-06	17%	1.3E-05	34%	3.3E-06	6%

Table 3-19
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Fisher

Western Site
RELMAP 50th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Fisher											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	7.2E-04	83%	5.2E-04	83%	4.5E-04	72%	3.3E-04	72%	2.3E-04	46%	1.7E-04	45%
Variant b:Small Municipal Waste Combustor	2.8E-04	55%	2.0E-04	55%	1.6E-04	25%	1.2E-04	24%	1.3E-04	8%	9.9E-05	8%
Large Commercial HMI	2.8E-04	56%	2.1E-04	55%	1.4E-04	13%	1.0E-04	13%	1.3E-04	3%	9.4E-05	3%
Large Hospital HMI	1.1E-03	89%	8.3E-04	89%	2.6E-04	52%	1.9E-04	52%	1.5E-04	19%	1.1E-04	19%
Small Hospital HMI	1.9E-04	35%	1.4E-04	35%	1.3E-04	6%	9.7E-05	6%	1.3E-04	1%	9.3E-05	1%
Large Hospital HMI (wet scrubber)	1.5E-04	19%	1.1E-04	19%	1.3E-04	3%	9.4E-05	3%	1.2E-04	1%	9.2E-05	1%
Small Hospital HMI (wet scrubber)	1.3E-04	1%	9.3E-05	1%	1.2E-04	0%	9.2E-05	0%	1.2E-04	0%	9.1E-05	0%
Large Coal-fired Utility Boiler	2.5E-04	51%	1.9E-04	51%	1.6E-04	23%	1.2E-04	23%	1.5E-04	20%	1.1E-04	20%
Medium Coal-fired Utility Boiler	1.9E-04	35%	1.4E-04	35%	1.7E-04	27%	1.2E-04	26%	1.5E-04	18%	1.1E-04	18%
Small Coal-fired Utility Boiler	1.6E-04	23%	1.2E-04	23%	1.4E-04	12%	1.0E-04	12%	1.3E-04	4%	9.5E-05	4%
Medium OIl-fired Utility Boiler	1.3E-04	2%	9.3E-05	2%	1.3E-04	2%	9.3E-05	2%	1.2E-04	1%	9.2E-05	1%
Chlor-alkali plant	8.2E-03	98%	6.0E-03	98%	9.6E-04	87%	7.0E-04	87%	3.1E-04	60%	2.2E-04	59%

Table 3-19 (continued)
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Subsistence Fisher

Western Site
RELMAP 90th percentile

	Predicted Ingestion (mg/kg/day) for Subsistence Fisher											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	8.7E-04	68%	6.4E-04	68%	6.1E-04	53%	4.4E-04	53%	3.9E-04	27%	2.8E-04	27%
Variant b:Small Municipal Waste Combustor	4.3E-04	35%	3.2E-04	35%	3.2E-04	13%	2.4E-04	12%	2.9E-04	4%	2.2E-04	4%
Large Commercial HMI	4.4E-04	36%	3.2E-04	35%	3.0E-04	6%	2.2E-04	6%	2.9E-04	1%	2.1E-04	1%
Large Hospital HMI	1.3E-03	78%	9.5E-04	78%	4.2E-04	32%	3.1E-04	32%	3.1E-04	9%	2.3E-04	9%
Small Hospital HMI	3.5E-04	19%	2.6E-04	19%	2.9E-04	3%	2.1E-04	3%	2.8E-04	1%	2.1E-04	1%
Large Hospital HMI (wet scrubber)	3.1E-04	9%	2.3E-04	9%	2.9E-04	1%	2.1E-04	1%	2.8E-04	0%	2.1E-04	0%
Small Hospital HMI (wet scrubber)	2.8E-04	1%	2.1E-04	1%	2.8E-04	0%	2.1E-04	0%	2.8E-04	0%	2.1E-04	0%
Large Coal-fired Utility Boiler	4.1E-04	32%	3.0E-04	31%	3.2E-04	12%	2.3E-04	11%	3.1E-04	10%	2.3E-04	10%
Medium Coal-fired Utility Boiler	3.5E-04	19%	2.6E-04	19%	3.3E-04	14%	2.4E-04	14%	3.1E-04	9%	2.3E-04	9%
Small Coal-fired Utility Boiler	3.2E-04	12%	2.3E-04	11%	3.0E-04	6%	2.2E-04	6%	2.9E-04	2%	2.1E-04	2%
Medium OIl-fired Utility Boiler	2.9E-04	1%	2.1E-04	1%	2.8E-04	1%	2.1E-04	1%	2.8E-04	0%	2.1E-04	0%
Chlor-alkali plant	8.3E-03	97%	6.1E-03	97%	1.1E-03	75%	8.2E-04	75%	4.7E-04	39%	3.4E-04	39%

Table 3-20
Western Site — RELMAP 50th and 90th Percentiles
Predicted Ingestion (mg/kg/day) for Recreational Angler

Western Site RELMAP 50th percentile	Predicted Ingestion (mg/kg/day) for Recreational Angler											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor			2.6E-04	83%			1.6E-04	73%			8.1E-05	47%
Variant b:Small Municipal Waste Combustor			9.9E-05	57%			5.8E-05	26%			4.7E-05	8%
Large Commercial HMI			1.0E-04	57%			4.9E-05	13%			4.4E-05	3%
Large Hospital HMI			4.1E-04	90%			9.2E-05	54%			5.4E-05	20%
Small Hospital HMI			6.8E-05	37%			4.6E-05	6%			4.3E-05	1%
Large Hospital HMI (wet scrubber)			5.3E-05	20%			4.4E-05	3%			4.3E-05	1%
Small Hospital HMI (wet scrubber)			4.4E-05	2%			4.3E-05	0%			4.3E-05	0%
Large Coal-fired Utility Boiler			9.0E-05	53%			5.6E-05	24%			5.4E-05	21%
Medium Coal-fired Utility Boiler			6.7E-05	36%			5.9E-05	28%			5.3E-05	19%
Small Coal-fired Utility Boiler			5.6E-05	24%			4.9E-05	12%			4.5E-05	4%
Medium OIl-fired Utility Boiler			4.4E-05	2%			4.4E-05	2%			4.3E-05	1%
Chlor-alkali plant			3.0E-03	99%			3.5E-04	88%			1.1E-04	61%

Western Site RELMAP 90th percentile	Predicted Ingestion (mg/kg/day) for Recreational Angler											
	2.5km				10 km				25km			
	Child		Adult		Child		Adult		Child		Adult	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor			3.2E-04	68%			2.2E-04	54%			1.4E-04	27%
Variant b:Small Municipal Waste Combustor			1.6E-04	36%			1.2E-04	13%			1.0E-04	4%
Large Commercial HMI			1.6E-04	36%			1.1E-04	6%			1.0E-04	1%
Large Hospital HMI			4.7E-04	79%			1.5E-04	33%			1.1E-04	10%
Small Hospital HMI			1.3E-04	20%			1.0E-04	3%			1.0E-04	1%
Large Hospital HMI (wet scrubber)			1.1E-04	10%			1.0E-04	1%			1.0E-04	0%
Small Hospital HMI (wet scrubber)			1.0E-04	1%			1.0E-04	0%			1.0E-04	0%
Large Coal-fired Utility Boiler			1.5E-04	32%			1.1E-04	12%			1.1E-04	10%
Medium Coal-fired Utility Boiler			1.3E-04	20%			1.2E-04	14%			1.1E-04	9%
Small Coal-fired Utility Boiler			1.1E-04	12%			1.1E-04	6%			1.0E-04	2%
Medium OIl-fired Utility Boiler			1.0E-04	1%			1.0E-04	1%			1.0E-04	0%
Chlor-alkali plant			3.0E-03	97%			4.1E-04	75%			1.7E-04	40%

Table 3-21
Eastern Site — RELMAP 50th and 90th Percentiles
Predicted Inhalation

Eastern Site	Predicted Inhalation for Eastern Site																	
RELMAP 50th percentile	2.5km						10km						25km					
	Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.6E-06	3%	4.9E-07	3%	3.3E-07	3%	1.6E-06	2%	4.9E-07	2%	3.3E-07	2%	1.6E-06	1%	4.8E-07	1%	3.2E-07	1%
Variant b:Small Municipal Waste Combustor	1.6E-06	1%	4.8E-07	1%	3.2E-07	1%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Large Commercial HMI	1.6E-06	1%	4.8E-07	1%	3.2E-07	1%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Large Hospital HMI	1.6E-06	3%	4.9E-07	3%	3.3E-07	3%	1.6E-06	1%	4.8E-07	1%	3.2E-07	1%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Small Hospital HMI	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Large Hospital HMI (wet scrubber)	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Small Hospital HMI (wet scrubber)	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Large Coal-fired Utility Boiler	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Medium Coal-fired Utility Boiler	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Small Coal-fired Utility Boiler	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Medium OIl-fired Utility Boiler	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%	1.6E-06	0%	4.8E-07	0%	3.2E-07	0%
Chlor-alkali plant	3.7E-06	58%	1.1E-06	58%	7.6E-07	58%	2.0E-06	21%	6.0E-07	21%	4.0E-07	21%	1.7E-06	8%	5.2E-07	8%	3.4E-07	8%

Eastern Site	Predicted Inhalation for Eastern Site																	
RELMAP 90th percentile	2.5km						10km						25km					
	Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.7E-06	3%	5.1E-07	3%	3.4E-07	3%	1.7E-06	2%	5.0E-07	2%	3.4E-07	2%	1.6E-06	1%	5.0E-07	1%	3.3E-07	1%
Variant b:Small Municipal Waste Combustor	1.6E-06	1%	5.0E-07	1%	3.3E-07	1%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Large Commercial HMI	1.6E-06	1%	5.0E-07	1%	3.3E-07	1%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Large Hospital HMI	1.7E-06	3%	5.1E-07	3%	3.4E-07	3%	1.6E-06	1%	5.0E-07	1%	3.3E-07	1%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Small Hospital HMI	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Large Hospital HMI (wet scrubber)	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Small Hospital HMI (wet scrubber)	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Large Coal-fired Utility Boiler	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Medium Coal-fired Utility Boiler	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Small Coal-fired Utility Boiler	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Medium OIl-fired Utility Boiler	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%	1.6E-06	0%	4.9E-07	0%	3.3E-07	0%
Chlor-alkali plant	3.8E-06	57%	1.1E-06	57%	7.7E-07	57%	2.0E-06	21%	6.2E-07	21%	4.1E-07	21%	1.8E-06	8%	5.3E-07	8%	3.5E-07	8%

Table 3-22
Western Site — RELMAP 50th and 90th Percentiles
Predicted Inhalation

Western Site	Predicted Inhalation for Western SIte																	
RELMAP 50th percentile	2.5km						10km						25km					
	Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.6E-06	2%	4.7E-07	2%	3.2E-07	2%	1.5E-06	2%	4.7E-07	2%	3.1E-07	2%	1.5E-06	1%	4.7E-07	1%	3.1E-07	1%
Variant b:Small Municipal Waste Combustor	1.5E-06	1%	4.6E-07	1%	3.1E-07	1%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Large Commercial HMI	1.5E-06	1%	4.7E-07	1%	3.1E-07	1%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Large Hospital HMI	1.6E-06	2%	4.7E-07	2%	3.2E-07	2%	1.5E-06	1%	4.6E-07	1%	3.1E-07	1%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Small Hospital HMI	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Large Hospital HMI (wet scrubber)	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Small Hospital HMI (wet scrubber)	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Large Coal-fired Utility Boiler	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Medium Coal-fired Utility Boiler	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Small Coal-fired Utility Boiler	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Medium OIl-fired Utility Boiler	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%	1.5E-06	0%	4.6E-07	0%	3.1E-07	0%
Chlor-alkali plant	3.3E-06	54%	1.0E-06	54%	6.8E-07	54%	1.8E-06	16%	5.5E-07	16%	3.7E-07	16%	1.6E-06	6%	4.9E-07	6%	3.3E-07	6%

Western SIte	Predicted Inhalation for Western SIte																	
RELMAP 90th percentile	2.5km						10km						25km					
	Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time		Child		Adult Full time		Adult Part time	
	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC	Value	%ISC
Variant b:Large Municipal Waste Combustor	1.6E-06	2%	4.8E-07	2%	3.2E-07	2%	1.6E-06	2%	4.8E-07	2%	3.2E-07	2%	1.6E-06	1%	4.7E-07	1%	3.2E-07	1%
Variant b:Small Municipal Waste Combustor	1.6E-06	1%	4.7E-07	1%	3.1E-07	1%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Large Commercial HMI	1.6E-06	1%	4.7E-07	1%	3.2E-07	1%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Large Hospital HMI	1.6E-06	2%	4.8E-07	2%	3.2E-07	2%	1.6E-06	1%	4.7E-07	1%	3.1E-07	1%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Small Hospital HMI	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Large Hospital HMI (wet scrubber)	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Small Hospital HMI (wet scrubber)	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Large Coal-fired Utility Boiler	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Medium Coal-fired Utility Boiler	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Small Coal-fired Utility Boiler	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Medium OIl-fired Utility Boiler	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%	1.5E-06	0%	4.7E-07	0%	3.1E-07	0%
Chlor-alkali plant	3.4E-06	54%	1.0E-06	54%	6.8E-07	54%	1.8E-06	16%	5.6E-07	16%	3.7E-07	16%	1.6E-06	6%	5.0E-07	6%	3.3E-07	6%

fruiting vegetables the bulk of mercury is also modeled to be the result of uptake of mercury from the atmosphere into the plant.

Although not shown in the tables below, divalent mercury accounts for approximately 90% of the total mercury intake for the agricultural scenarios, with the rest being methylmercury. This partitioning is reflective of the predicted speciation of mercury in the ingested plant and animal products.

The differences between facilities are due to differences in parameters that affect effective stack height, and the assumed total mercury emission rate. The speciation of mercury emissions is not an important factor because the speciation only affects the predicted deposition rates, not the total mercury air concentrations.

3.2.3 Urban Scenarios

With the exception of the child exhibbiting pica behavior in this scenario (urban high end child), the predicted mercury exposures in the urban scenarios are generally an order of magnitude lower than those for the agricultural scenarios. This reflects the lower ingestion rates assumed for locally grown plant products. As for the agricultural scenarios, divalent mercury is the primary form of mercury to which they receptors are exposed.

The larger contribution of the local sources in these scenarios reflects the fact that only for the urban high end is consumption of plant products assumed: for the other urban scenarios exposure to mercury from the local source is assumed to be solely through ingestion of soil. The contributions of the local source shown for the urban scenarios thus reflect the contribution of the local source on the soil concentrations, which themselves are driven by the mercury deposition rates. The mercury deposition rates are generally driven by the assumed speciation of mercury emissions.

The contribution of the local source when pica behaviour is exhibbited (urban high end child) reflects the contribution of the local source to the soil concentration.

3.2.4 Fish Ingestion Scenarios

The predicted mercury exposure in the fish ingestion scenarios (high-end fisher and recreational angler) is dominated by exposure through ingestion of fish, even though some exposure through ingestion of plant products is also assumed. Methylmercury is the primary form of mercury to which these receptors are exposed. The fish concentrations are driven by the predicted dissolved methylmercury concentrations in the surface water, which themselves are driven by the watershed soil concentrations and the waterbody atmospheric mercury deposition rate.

For several of the facilities at both the eastern and western sites, the majority of the exposure to mercury is predicted to be due to the local source for the waterbody located 2.5 km from the facility. This is also true for some facilities at both 10 km and 25 km. These results reflect the contribution of the local source to total mercury deposition onto the waterbody and the watershed soils.

The contribution of the local source is larger at the western site because both the regional and pre-industrial deposition rates are lower than at the eastern site, while the results for the local source (using ISC) are more similar. However, the total mercury exposure is approximately twice as low at the drier western site compared to the eastern site due primarily to differences in meteorology.

3.3 Issues Related to Predicted Mercury Exposure Estimates

In the modeling effort exposure for six different hypothetical adult humans was modeled. Atmospheric emissions of anthropogenic origin, local background and regional atmospheric mercury may not be the only sources of mercury exposure. Individuals can be exposed to mercury from other sources such as occupation and consumption of non-local (e.g., marine) fish. Quantitative estimates of these sources are presented in the following chapters of this Volume. This section considers the logic of adding exposure from these additional sources in an assessment.

Occupational mercury may be an important source of exposure. This source may apply to any hypothetical adult modeled here with the exception of the subsistence farmer. For a given area with a relevant industrial base, it may be appropriate to consider these exposures for members of the population, when assessing mercury exposures.

In the modeling effort several hypothetical humans were assumed not to consume locally-caught fish. These hypothetical individuals include: a subsistence farmer and child, a rural home gardener, and the urban dwellers. For these hypothetical individuals, it is reasonable to assume that some fraction of the individuals they represent will consume marine fish. For this marine fish consuming subset, the ranges of methylmercury exposure from marine fish consumption that are estimated later in this Volume are applicable. Methylmercury from marine fish consumption, if considered, is an incremental increase over the estimated intakes.

In the modeling effort several hypothetical individuals were assumed to consume high levels of locally caught fish. These individuals include: an angler, who is assumed to consume 60 grams of local fish/day, a child, who is assumed to consume 20 grams of local fish/day and a recreational angler who is assumed to consume 30 grams fish/day. Since these hypothetical individuals consume high levels of local fish, it is probably inappropriate to consider exposure through an additional fish consumption pathway. Although it is reasonable to assume that some individuals consume both local and other fish; for example, Fiore et al. (1989) documented the consumption of both self-caught and purchased fish in U.S. anglers, these data are not combined in this assessment.

The initial conditions assumed before the facility is modeled (referred to here as “background”) are potentially critical to the total mercury exposure. This is particularly important because the magnitude of the contribution of a local source to the total may be used to assess its impact. A delicate balance is required when including such a “background” in the analysis. This is because it is not just a matter of a local source’s contribution to this background, but the total impact of background plus the local source that is ultimately the primary concern. Overestimating the background will result in a concurrent decrease in the contribution of a given local source, but may result in exceeding thresholds that would not be exceeded if lower estimates of background are assumed. Resolution of this issue is not within the objectives of the current report; it is noted, however, that there is no available guidance on how to incorporate background in exposure assessment. For a local scale mercury exposure assessment it is important to measure mercury concentrations in various media.

The impact of the uncertainty in the predicted air concentrations and deposition rates for each facility is most important for the fish ingestion and pica child scenarios. This is because, in general, the local source does not contribute significantly to the mercury exposure for the agricultural and urban scenarios. The exception to this pattern is the chlor-alkali model plant. In this case, the low assumed mercury release height results in the facility having a substantial impact on the mercury air concentrations close to the facility.

3.4 Summary Conclusions

- The contribution of the local source, compared to background and the regional contribution, is larger at the western, drier site than at the eastern site. This is because both the regional impact and background values are much lower at the western site than is prdicted to occur for the local source. However, the magnitude of the total exposure at the western site is about half that at the eastern site due to the drier meteorology at the western site.

- For the agricultural scenarios, it is generally the background or regional sources that account for the majority of total mercury exposure. This is because the dominant pathway of mercury exposure in these scenarios is the ingestion of plants, which accumulate most of their mercury from the air, and most of the local sources are predicted to have little impact on the local average air concentrations compared to the regional sources.

- Most of the mercury to which the hypothetical receptor is exposed in the agricultural and urban scenarios is divalent mercury. This is because most of the mercury in plants and soil is predicted to be of this form. In contrast, in the fish ingestion scenairos methylmercury is the primary form of mercury to which the receptor is exposed.

- For the fish ingestion scenarios, the local sources are predicted to account for the majority of the total mercury exposure for waterbodies close to the facility. This is particularly true for the western site, where the background and regional contribution tothe total mercury deposition are lower.

4. POPULATION EXPOSURE — FISH CONSUMPTION

4.1 Fish Consumption among the General U.S. Population

Fish bioaccumulate methylmercury through the freshwater aquatic and marine food-chains. Mercury-contaminated phytoplankton and zooplankton are consumed by planktivorous fish (referred to in other parts of this Volume at trophic level 3 fish). Methylmercury is thought to bioaccumulate in this group as well as in the piscivorous fish. Both marine and freshwater fish bioaccumulate methylmercury in their muscle tissue. Consumption of these methylmercury-contaminated fish results in exposures to human populations. Additional data have become available between 1995 and 1997 that permit estimates of mercury consumption from marine mammals and birds by populations living in the far Northern latitudes.

Consumption of fish is highly variable across the U.S. population unlike consumption of other dietary components, such as bread or starch, that are almost ubiquitously consumed. This chapter presents an estimate of the magnitude of fish consumption in both the general U.S. population and in specific subpopulations (e.g., children and women of child-bearing age). This estimate identified the portion of the population that consumes fish and shellfish. It also provides estimates of species of fish consumed and the quantity of fish consumed based on cross-sectional survey data. Use of a national data base differentiates data in this Chapter from site-specific assessments. Data presented in this Chapter differ from site-specific assessments in which consumption of contaminated local freshwater fish are included.

Inclusion of fish in the diet varies with geographic location, seasons of the year, ethnicity, and personal food preferences. Data on fish consumption have been calculated typically as either on “per capita” or “per user” basis. The former term is obtained by dividing the supply of fish across an entire population to establish a “per capita” consumption rate. The latter term divides the supply of fish across only the portion of the population that consumes fish, providing “per user” rates of consumption.

Identifying differences in fish consumption rates for population groups can be achieved through analysis of dietary survey data for the general United States population and specified subpopulations; e.g., some Native American tribes, recreational anglers, women of childbearing age, and children. The United States Department of Agriculture (USDA) has conducted a series of nationally-based dietary surveys, including the 1977-1978 Nationwide Food Consumption Survey and the Continuing Surveys of Food Intake by Individuals (CFSII) over the period 1989 through 1995 (CFSII 89-91; CSFII, 1994; CFSII, 1995). In addition, data from the third National Health and Nutrition Examination Survey (NHANES III), conducted between 1988 and 1994, provide estimates of fish consumption patterns in the early 1990s. Analyses of fish consumption patterns among the general U.S. population and selected age/gender groupings are described below. Fish consumption rate data from specific Native American tribes and angling populations are identified and used to corroborate the nationwide fish consumption data.

4.1.1 Patterns of Fish Consumption

Although the consumption frequency of fish is low compared with staple foods such as grain products, dietary intake of fish can be estimated from survey data. The initial issue of how to estimate fish consumption depends to a great extent on the choice of dietary assessment method. Available techniques include long-term dietary histories, questionnaires to identify typical food intake or short-term dietary recall techniques and questionnaires on food frequency. The first consideration is to obtain dietary information that reflects typical fish consumption. A true estimate of methylmercury intake from fish is complicated by changes in fish intake over time, differences in species of fish consumed, variation in the methylmercury concentration in a species of fish, and broad changes in the sources of fish entering the U.S. market place. For example, increases in aquaculture or fishfarming and increased reliance on imported fish for domestic consumption may affect consumption estimates. Temporal variation in dietary patterns is an issue to consider in the evaluation of short-term recall/record data. For epidemiological studies that seek to understand the relationship of long-term dietary patterns to chronic disease, typical food intake is the relevant parameter to evaluate (Willett, 1990).

Because methylmercury is a developmental toxin that may produce adverse effects following a comparatively brief exposure period (i.e., a few months rather than decades), comparatively short-term dietary patterns can have importance. Consequently, estimation of recent patterns of methylmercury consumption from fish is the relevant exposure for the health endpoint of concern. Because it is not possible to precisely identify the period of development during which mercury is likely to damage the nervous system of the developing fetus or growing child, exposure of women of childbearing age or your children to mercury via consumption of fish is a cause for concern.

This chapter describes the distribution of fish intakes for the general population and for subpopulations defined by age or gender; e.g., women of child-bearing age. Estimates of the number of women who are pregnant in any given year are based on methods shown in Appendix B. The analysis is not intended to estimate fish consumption by an individual and relate it to an individual's health outcomes. Dietary questionnaires or dietary histories may identify broad patterns of fish consumption, but these techniques provide less specific recollection of foods consumed such as the species of fish eaten. Likewise estimates of the quantity of fish consumed become less precise as the eating event becomes more remote in time. The selection of a dietary survey method to describe fish intakes by the subpopulation of interest requires a balancing the specificity of information collected with the generalization of short-term dietary patterns to longer-term food intakes.

After the appropriate period of fish intake is selected, the second area of concern becomes the variation in the methylmercury concentrations of the fish consumed. A central feature of food intake among subjects with a free choice of foods is the day-to-day variability in foods consumed superimposed on an underlying food intake pattern (Willett, 1990). In epidemiology studies, an individual's true intake of a food such as fish could be considered as the mean intake for a large number of days. Collectively, the true intakes by these individuals define a frequency distribution for the study population as a whole (Willett, 1990). It is rarely possible to measure a large number of days of dietary intake for individual subjects; consequently, a sample of one or several days is used to represent the true intake (Willett, 1990). The effect of this sampling is to increase artifically the standard deviation, i.e., to broaden the tails of the distribution (Willett, 1990). This results in estimates of intake that are both larger and smaller than the true long-term averages for any subject. Overall, authorities in nutritional epidemiology (among others see Willett, 1990) conclude that "measurements of dietary intake based on a single or small number of 24-hour recalls per subject may provide a reasonable (unbiased) estimate of the mean of a group, but the standard deviation will be greatly overestimated."

Assessment of recent dietary intakes can be achieved through dietary records for various periods (typically 7-day records or 3-day records) or dietary recall (typically 24-hour recalls or 3-day recalls) (among others see Witschi, 1990). Questions on food frequency in dietary histories can be used to estimate how often a population consumes fish and shellfish. Research is currently in progress to estimate usual intake distributions that account for intake data of foods that are not consumed on a daily basis (among others see Nusser et al. 1996). In 1996, Nusser et al. published a statistical approach to estimating moderate-term (e.g., months) patterns of food consumption based on multiple 24-hour dietary recalls obtained from the same individual.

Sources of error in short-term recalls and records affect all dietary survey methodologies. These include errors made by the respondent or recorder of dietary information as well as the interviewer or reviewer. Information used to calculate the intake of the chemical of interest is another source of error. The detection limit of the analyte, the frequency of zero and trace values, and how such values are managed can statistically influence the accuracy of the mean mercury concentration for a fish species. The third source of error in dietary assessments is the data base used to calculate intakes of the chemical from the food consumed, for example the data may no longer reflect current concentrations of the chemical in foods.

The ability of the subject to remember the food consumed and in what quantities it was consumed is central to these methods (among many others see Witschi, 1990). In an analysis of data from the National Health and Nutrition Evaluation Survey (NHANES), the largest source of error was uncertainty of subjects about foods consumed on the recall day (Youland and Engle, 1976). Fish consumption appears to be more accurately remembered than most other food groups. Karvetti and Knuts (1985) observed the actual intake of 140 subjects and later interviewed them by 24-hour recall. They found that fish was omitted from the dietary recall less than 5% of the time and erroneously recalled approximately 7% of the time. The validity of 24-hour recalls for fish consumption was greater than all other food groups. Interviewer and reviewer errors can be reasonably predicted to be consistent for a given survey and unlikely to affect reporting of fish consumption selectively.

4.1.1.1 Estimates of Fish Intake for Populations

Data on fish consumption have been calculated typically as either "per capita" or "per user". The former term is obtained by dividing the supply of fish across an entire population to establish a "per capita" consumption rate. The latter term divides the supply of fish across only the portion of the population that consumes fish; i.e., "per user" rates of consumption.

Survey methods can broadly be classified into longitudinal methods or cross-sectional surveys. Typically long-term or longitudinal estimates of intake can be used to reflect patterns for individuals (e.g., dietary histories); or longitudinal estimates of moderate duration (e.g., month-long periods) for individuals or groups. Cross-sectional data are used to give a "snap shot" in time and are typically used to provide information on the distribution of intakes for groups within the population of interest. Cross-sectional data typically are for 24-hour or 3-day sampling periods and consist of recall of foods consumed in response to questioning by a trained interviewer, or they may be taken from written records of foods consumed.

During the past decade, reviewers of dietary survey methodology (for example, the Food and Nutrition Board of the National Research Council/National Academy of Sciences; the Life Sciences Research Office of the Federation of American Societies of Experimental Biology) have evaluated various techniques with regard to their suitability for estimating exposure to contaminants and intake of nutrients. The Food and Nutrition Board of the National Research Council/National Academy of Sciences in their 1986 publication on *Nutrient Adequacy Assessment Using Food Consumption Surveys* noted that dietary intake of an individual is not constant from day to day, but varies on a daily basis both in amount and in type of foods eaten (intraindividual variation). Variations between persons in their usual food intake averaged over time is referred to as interindividual variation. Among North American populations, the intraindividual variation is usually considered to be as large as or greater than the interindividual variation. Having evaluated a number of data sets, the Academy's Subcommittee concluded that three days of observation may be more than is required for the derivation of the distribution of usual intakes.

Major sources of data on dietary intake of fish used in preparing this Report to Congress are the cross-sectional data from the USDA CSFII conducted from 1989 through 1995 (CSFII 89-91; CSFII 1994; and CSFII 1995); on cross-sectional data from the NHANES III conducted between 1988 and 1994; and the longer-term data on fish consumption based on recorded fish consumption for various numbers of one-month periods of time during the years 1973-1974 by the National Purchase Diary (NPD 73-74) conducted by the Market Research Corporation. Longer-term data on fish consumption has also been obtained from questions on frequency of fish consumption that were included in the NHANES III survey and in CSFII 1994 and CSFII 1995.

Identifying differences in fish consumption rates for population groups can be achieved through analysis of dietary survey data for the general U.S. population and specified subpopulations; e.g., some tribes of Native Americans including Alaskan tribes, and recreational anglers. The USDA has conducted a series of nationally-based dietary surveys including the 1977-1978 Nationwide Food Consumption Survey and the Continuing Surveys of Food Intake by Individuals over the period 1989 through 1991 (CSFII 89-91, CSFII

1994, and CSFII 1995), as well as the National Center for Health Statistics stratified population based examination survey conducted between 1988 and 1994 (NHANES III). Analyses of fish consumption patterns among the general U.S. population are described below.

4.1.1.2 Estimates of Month-Long Fish and Shellfish Consumption from Cross-sectional Data

The adverse developmental effects of methylmercury ingestion are closely associated with the cumulative quantity of methylmercury consumed. The period of development that is critical to the expression of adverse developmental effects is not known with precision. In humans, the critical exposure period is thought to be comparatively short-term based on the methylmercury poisoning outbreak in Iraq and various case reports of *in utero* methylmercury poisoning (see the Human Health and Risk Characterization Volumes for additional information). Consequently, it is important to be able to predict moderate-term exposures from cross-sectional data on methylmercury exposure.

Estimates of a single day's exposure to methylmercury can be calculated from 24-hour recall data. The quantity of fish/shellfish (portion size) and species of fish/shellfish consumed by an individual over a day can be used to calculate daily intake of fish/shellfish. The 24-hour recall data describe portion size and species of fish consumed. By including the amount of mercury present in this amount of fish, an estimate of mercury ingestion can be made. This provides the distribution of mercury intakes for a 24-hour or 1-day period. Dividing total mercury intake per day by the person's body weight permits calculation of µg Hg/kg*bw*/day. Ranking these estimates by increasing quantity permits identification of various percentiles; e.g., 50th, 90th, 95th, etc. These rankings are the basis for "per user" percentiles.

The projection of daily dietary exposure to methylmercury (i.e., µg/kg*bw*/day) to exposure for a moderate period of time (e.g., months) has been a well-recognized complication of using dietary data. If multiple 24-hour recall data for an individual are available, Nusser et al. (1996) have described a statistical method for projecting moderate-term dietary intakes. Publication of this methodology is comparatively recent and the computer software/hardware requirements for these statistical analyses are somewhat complex. Consequently, another approach for projecting month-long fish/shellfish consumption and methylmercury exposures was needed.

The number of days per month that an individual consumes methylmercury from diet can be estimated from data on frequency of fish/shellfish consumption. The NHANES III included questions on how often per day/week/month, over the past 12-months, an individual consumed fish and shellfish. These data are described below (Section 4.1.2.2) for persons 12 years of age and older. Children under 12 years-of-age were not part of the respondents in NHANES III who were asked about frequency of fish and shellfish consumption. Accordingly, the authors of this report have made the simplifying assumption that the frequency of fish consumption for adults from the same ethnic, racial, and economic groups can be applied to estimates of fish and shellfish intake for children. Estimates of mercury exposure based on a single day's intake (µg/kg*bw*/day) specific for individual child survey participants were available from the 24-hour recall data in NHANES III. These data and the adult's frequency of fish consumption data were used to estimate month-long projections of methylmercury exposures for children.

4.1.1.3 1973 and 1974 National Purchase Diary Data

The National Purchase Diary 1973-74 (NPD 73-74) data are based on a sample of 7,662 families (25,165 individuals) out of 9,590 families sampled between September 1973 and August 1974 (SRI International Contract Report to U.S. EPA, 1980; Rupp et al., 1980). Available reports are not entirely clear on how the subsample of 7,662 was chosen. Fish consumption was based on questionnaires completed by the female head of the household in which she recorded the date of any meal containing fish, the type of fish (species), the packaging of the fish (canned, frozen, fresh, dried, or smoked, or eaten out), whether fresh fish was recreationally caught or commercially purchased, the amount of fish prepared for the meal, the number of servings consumed by each family member and any guests, and the amount of fish not consumed during the meal. Meals eaten both at home and away from home were recorded. Ninety-four percent of the respondents reported consuming seafood during the sampling period.

Use of these data to estimate intake of fish or mercury on a body weight basis is limited by the following data gaps:

1. This survey did not include data on the quantity of fish represented by a serving and information to calculate actual fish consumption from entries described as breaded fish or fish mixed with other ingredients. Portion size was estimated by using average portion size for seafood from the USDA Handbook # 11, Table 10, page 40-41. The average serving sizes from this USDA source are shown in Table 4-1.

Table 4-1
Average Serving Size (gms) for Seafood from
USDA Handbook # 11 Used to Calculate
Fish Intake by FDA (1978)

Age Group (years)	Male Subjects (gms)	Female Subjects (gms)
0-1	20	20
1-5	66	66
6-11	95	95
12-17	131	100
18-54	158	125
55-75	159	130
Over 75	180	139

2. There may have been systematic under-recording of fish intake as it was noted that typical intakes declined 30% between the first survey period and the last survey period among persons who completed four survey diaries (Crispin-Smith et al., 1985).

3. There have been changes in the quantities and types of fish consumed between 1973-1974 and present. The USDA (Putnam, 1991) indicated that, on average, fish consumption increased 27% between 1970 to 1974 and 1990. This increase is also noted by the National Academy of Sciences in *Seafood Safety* (1991). Whether or not this increase applies to the highest percentiles of fish consumption (e.g., 95th or 99th percentile) was not described in the USDA publication.

   Changes in the types of fish consumed have been noted. For example, Heuter et al. (1995) noted that there is currently a much greater U.S. consumption of shark compared to past decades.

4. Although the NPD data with the sample weights were used to project these data to the general U.S. population (SRI International under U.S. EPA Contract 68-01-3887), in 1980, U.S. EPA was subsequently informed that the sample weights were not longer available. Consequently, additional analyses with these data, in a manner than can be projected to the general population, no longer appear to be possible.

5. Body weights of the individuals surveyed do not appear in published materials. If body weights of the individuals participating in this survey were recorded these data do not appear to have been used in subsequent analyses.

Data on fish consumption from the NPD 73-74 survey have been published by Rupp et al. (1980) and analyzed by U.S. EPA's contractor SRI International (1980). These data indicate that when a month-long survey period is used, 94% of the surveyed population consumed fish. The species of fish most commonly consumed are shown in Table 4-2.

Table 4-2
Fish Species and Number of Persons Using the Species of Fish.
(Adapted from Rupp et al., 1980)

Category	Number of Individuals Consuming Fish Based on 24,652 Replies*
Tuna, light	16,817
Shrimp	5,808
Flounders	3,327
Not reported (or identified)	3,117
Perch (Marine)	2,519
Salmon	2,454
Clams	2,242
Cod	1,492
Pollock	1,466

* More than one species of fish may be eaten by an individual.

Rupp et al. (1980) also estimated quantities of fish and shellfish consumed by teenagers aged 12-18 years and by adults aged 18 to 98 years. These data are shown in Table 4-3. The distribution of fish consumption for age groups that included women of child-bearing ages are shown in Table 4-4.

Table 4-3
Fish Consumption from the NPD 1973-1974 Survey
(Modified from Rupp et al., 1980)

Age Group	50th Percentile	90th Percentile	99th Percentile	Maximum
Teenagers Aged 12-18 Years	1.88 kg/year	8.66 kg/year	25.03 kg/year or 69 grams/day	62.12 kg/year
Adults Aged 18 to 98 Years	2.66 kg/year	14.53 kg/year	40.93 kg/year or 112 grams/day	167.20 kg/year

Table 4-4
Distribution of Fish Consumption for Females by Age*
Consumption Category (gms/day) (from SRI, 1980)

Age (years)	47.6-60.0	60.1-122.5	Over 122.5
10-19	0.2	0.4	0.0
20-29	0.9	0.9	0.0
30-39	1.9	1.7	0.1
40-49	3.4	2.1	0.2

* The percentage of females in an age bracket who consume, on average, a specified amount (grams) of fish per day. The calculations in this table were based upon the respondents to the NPD survey who consumed fish in the month of the survey. The NPD Research estimates that these respondents represent, on a weighted basis, 94.0% of the population of U.S. residents (from Table 6, SRI Report, 1980).

4.1.1.4 Nationwide Food Consumption Survey of 1977-78

Fish consumption is not evenly divided across the U.S. population. Analysis of patterns of fish consumption have been performed on data obtained from dietary surveys of nationally representative populations. For example, Crochetti and Guthrie (1982) analyzed the food consumption patterns of persons who participated in the Nationwide Food Consumption Survey of 1977-78. Populations specifically excluded from this analysis were children under four years of age, pregnant and nursing women, vegetarians, individuals categorized by race as "other" (i.e., not "white" and not "black"), individuals not related to other members of the household in which they lived, and individuals with incomplete records. After these exclusions, the study population consisted on 24,085 individual dietary records for a 3-day period.

Persons reporting consumption of fish, shellfish, and seafood at least once in their 3-day dietary record were categorized as fish consumers. Combinations of fish, shellfish, or seafood with vegetables and/or starches (e.g., rice, pasta) or fish sandwiches were categorized as consumers of fish "combinations". Among the overall population, 25.0% of respondents reported consumption of fish with an additional 9.6% reporting consumption of fish "combinations" in the 3-day period for a total of 34.6% reporting consumption of fish and/or fish combinations. Frequency of consumption was comparable for male and female respondents with 24.1% of men and 25.7% of women reporting consumption of fish in their 3-day dietary records. Fish "combinations" were reported as dietary items by 11.2% of women and 9.9% of men. Both these food categories were consumed typically as mid-day and evening meals, rather than as breakfast or as snacks. For persons who listed fish in their 3-day dietary records, 89.7% listed fish in one meal only with 10.1% of respondents consuming fish in two meals and 0.1% consuming fish in three meals. For dishes that combined fish and other foods (i.e., fish "combinations"), among persons who reported eating fish combinations, 93.4% reported this food in one meal only with 6.5% of individuals consuming two meals containing fish "combinations."

There appears to be little difference between men and women in their likelihood of consuming fish based on patterns observed in this national survey (Crochetti and Guthrie, 1982). Based on this analysis, allocation of fish consumption on a "per capita" basis does not adequately reflect the fish consumption patterns of the general population of the United States. While "per capita" estimates resulted in an overestimate of fish consumption for the approximately 65% of the U.S. population who did not report consuming fish, these types of estimates by their nature substantially underestimated fish consumption rates by persons who consume fish. This pattern of underestimation is important in an assessment of impact of infrequently consumed foods such as fish.

4.1.1.5 CSFII 1989-1991

The second set of nation-wide data (CSFII 89-91) are presented in Table 4-5, including an age/gender analysis of the fish-consuming population. Based on analysis of 11,706 respondents who supplied 3-days of dietary record in the CSFII of 1989-1991, the frequency of fish consumption within the 3-day period was determined. Analyses of these dietary records indicate that 30.9% of respondents consumed fish, either alone or as part of a dish that contained fish. Most respondents eating fish consumed one fish meal within the 3-day period. Two percent (2%) of respondents reported consuming fish two or more times during the 3-day period, and 0.5% of these fish-eating respondents reported fish consumption three or more times during the 3-day study period. Among persons who reported eating fish within the 3-day period of the survey, 44.1% reported eating marine finfish (other than or in addition to tuna, shark, barracuda, and swordfish). Marine finfish were more frequently consumed than freshwater fish. Of the 1593 people who reported eating finfish, 492 (30.9%) identified these as freshwater fish.

Table 4-5
CSFII 89-91 Data

Gender	Aged 14 Years or Younger	Aged 15 through 44 Years	Aged 45 Years or Older	Total for All Age Groups
Number of Individuals With 3 Days of Dietary Records				
Males	1497 (51.7%)	2131 (42.9%)	1537 (40.0%)	5,165 (44.1%)
Females	1396 (48.3%)	2837 (57.1%)	2308 (60.0%)	6,541 (55.9%)
Total	2893 (24.7%)	4968 (42.4%)	3845 (32.8%)	11,706
Respondents Reporting Consumption of All Fish and Shellfish (Data weighted to be representative of the U.S. population.)				
Males	380 (52.8%)	646 (42.8%)	556 (39.3%)	1582 (43.8%)
Females	340 (47.2%)	864 (57.2%)	828 (58.5%)	2032 (56.2%)
Total	720 (19.9%)	1510 (41.8%)	1415 (39.2%)	3614 (30.9%)

4.1.1.6 CSFII 1994 and CSFII 1995

Analyses in 1994 were based on 5296 respondents on day 1 and 5293 respondents on day 2. A change in survey methods resulted in food consumption data being collected for two days rather than for three days as in the 1989-91 survey. Dietary records included fish or shellfish for 598 individuals on day 1 and 596 individuals for day 2. These days were not necessarily sequential. Fish/shellfish consumption by age and gender categories for CSFII 1994 and CSFII 1995 are shown in Tables 4-6 and 4-7, respectively. Overall, 11.3% of respondents reported fish or shellfish consumption. The rate was lower among children under 15 years of age and higher among adults aged 45 years and older.

Table 4-6
CSFII 1994 Data — Days 1 and 2

Gender	Aged 14 Years or Younger	Aged 15 through 44	Aged 15 and Older	Total for All Age Groups
Number of Individuals with Dietary Recalls — Day 1				
Males	932	852	869	2653
Females	942	842	859	2643
Total	1874	1694	1728	5296
% consumption fish	7.9	10.9	15.4	11.3
Respondents Reporting Consumption of All Fish and Shellfish — Day 1				
Males	65	90	138	293
Females	83	94	128	305
Total	148	184	266	598
Number of Individuals with Dietary Recalls — Day 2*				
Males	993	852	868	2653
Females	941	840	859	2640
Total	1874	1692	1727	5293
% consumption fish	8.6	10.2	15.1	11.3
Respondents Reporting Consumption of All Fish and Shellfish — Day 2				
Males	74	86	132	292
Females	88	87	129	304
Total	162	173	261	596

*__Methodology changes based on two 24-hour recalls, not necessarily sequential.__

To assess whether or not there were seasonal differences in fish and shellfish consumption, the year was divided into six two-month intervals. Fish intake data was analyzed by season. These values are shown in Table 4-8.

Table 4-7
CSFII 1995 Data — Days 1 and 2

Gender	Aged 14 Years or Younger	Aged 15 through 44	Aged 15 and Older	Total for All Age Groups
Number of Individuals with Dietary Recalls — Day 1				
Males	863	649	1,067	2,579
Females	808	635	1,041	2,484
Total	1,671	1,284	2,108	5,063
% Consuming Fish	7.5	11.7	15.4	11.9
Respondents Reporting Consumption of All Fish and Shellfish — Day 1				
Males	63	77	170	310
Females	63	73	155	291
Total	126	150	325	601
Number of Individuals with Dietary Recalls — Day 2				
Males	862	648	1,067	2,577
Females	809	634	1,042	2,485
Total	1,671	1,282	2,109	5,062
% Consuming Fish	8.8	12.9	14.5	12.2
Respondents Reporting Consumption of All Fish and Shellfish — Day 2				
Males	81	82	168	331
Females	67	84	138	289
Total	148	166	306	620

Table 4-8
Fish Consumption (gms) by Season for Respondents Reporting Seafood Consumption
CFSII 1994 — Day 1

Statistics	Season					
	Jan/Feb	Mar/Apr	May/Jun	Jul/Aug	Sep/Oct	Nov/Dec
Mean	102	92	92	107	100	105
Std. Dev*	74	74	82	87	77	77
Minimum	2	1	2	1	2	2
Maximum	373	488	960	903	413	517

Table 4-8 (continued)
Fish Consumption (grams) by Season for Respondents Reporting Seafood Consumption
CFS II 1994 — Day 1

Statistics	**Season**					
	Jan/Feb	**Mar/Apr**	**May/Jun**	**Jul/Aug**	**Sep/Oct**	**Nov/Dec**
Percentiles						
5th	14	10	22	21	12	14
10th	28	19	28	28	23	24
25th	50	51	42	53	49	48
Median	86	73	57	85	79	85
75th	114	123	118	139	129	165
90th	202	173	190	196	204	189
95th	293	227	295	272	253	235
Observations	183	219	210	242	191	163
Sum of Weights (000s)	10,197	11,383	11,817	11,506	9,573	9,113

***** The values in these cells are the weighted standard deviations of the individual observations. Estimates of the standard errors of the means were not calculated.

4.1.1.7 NHANES III General Description

The NHANES III, conducted between 1988 and 1994, used a multistage probability design that involved selection of primary sampling units, segments (clusters of households) within these units, households, eligible persons, and finally sample persons. Primary sampling units typically were composed of a county or group of contiguous counties. Certain subgroups in the population that were of special interest for nutritional assessment were oversampled: preschool children (six months through five years old)[1], persons 60 through 74 years old, and the poor (persons living in areas defined as poor by the United States Bureau of the Census for the 1990 census). The U.S. Bureau of the Census selected the NHANES III sample according to rigorous specifications from the National Center for Health Statistics so that the probability of selection for each person in the sample could be determined.

The statistics presented in the report are population estimates. The findings for each person in the sample were inflated by the reciprocal of selection probabilities, adjusted to account for persons who were not examined, and stratified afterward according to race, sex and age, so that the final weighted population estimates closely approximated the civilian noninstitutionalized population of the United States as estimated independently by the U.S. Bureau of the Census at the midpoint of the survey, March 1, 1990.

[1]Although children are oversampled in the survey design, not all assessmsents were carried out among young children. For example, 24-hour dietary recall data were obtained for children, however, frequency of fish consumption information was not obtained.

Although NHANES III was conducted between 1988 and 1994, data on food consumption only became available in 1996. The survey includes one 24-hour recall obtained by a trained interviewer. This data base contains 29,973 dietary records including 3864 individuals who consumed fish and shellfish (Table 4-9). Consumption of fish differed by age. Overall 12.9% of respondents included fish or shellfish in their 24-hour dietary recall. As observed in CSFII 1994, the data among children aged 14 years and younger was about half the percentages of fish consumption for ages 45 and older (Tables 4-10 and 4-11). There were questions on frequency of fish/shellfish consumption in the CSFII 1994 and CSFII 1995 data bases; however, the specific information obtained excluded canned fish. Consequently, these data were not used to estimate month-long fish consumption. The 24-hour recall data were analyzed for both children and adults.

Table 4-9
All Age Groups NHANES III

	Ages 14 and Younger	**Ages 15 through 44 Years**	**Ages 45 and Older**	**Total**
Total	12,048	10,041	7,884	29,973
Fish Consumption	1060	1527	1274	3861
% Consumption Fish	8.8	15.2	16.2	12.9

Table 4-10
NHANES III Adult Respondents

Gender	**Ages 15 to 44 Years**	**Age 45 Years and Older**	**Total for All Age Groups**
Total Respondents			
Males	4,620	3,783	8,403
Females	5,421	4,101	9,522
Total	10,041	7,884	29,989
Respondents Reporting Fish Consumption			
Males	664	605	1269
Females	883	645	1528
Total	1527	1274	2801

Table 4-11
NHANES III Child Respondents

Age Group	Total	Fish Consumers	% Reporting Fish
1-5 Years	7595	626	8.2
6-11 Years	3217	323	10.0
12-14 Years Female	660	58	8.8
12-14 Years Male	576	53	9.2
Total	12,048	1060	8.8

4.1.2 Frequency of Consumption of Fish Based on Surveys of Individuals

4.1.2.1 CSFII 1989-1991

In the USDA 1989 through 1991 Continuing Surveys of Food Intake by Individuals (CSFII 89-91), food consumption data were obtained from nationally representative samples of individuals. These surveys included women of child-bearing age — 15 through 44 years of age. Data from the CSFII for the period including 1989 and 1991 were used to calculate fish intake by the general population and women of child-bearing age. This subpopulation included pregnant women, which are a subpopulation of interest in the Mercury Study: Report to Congress, because of the potential developmental toxicity to the fetus accompanying ingestion of methylmercury. Analysis of *Vital and Health Statistics* data from 1990 indicated that 9.5% of women in this age group can be predicted to be pregnant in a given year. The size of this population has been estimated using the methodology described in the Addendum to this chapter, entitled "Estimated National and Regional Populations of United States Women of Child-Bearing Age."

The data described in this section were obtained from nationally representative samples of individuals and were weighted to reflect the U.S. population using the sampling weights provided by USDA. The basic survey was designed to provide a multistage stratified area probability sample representative of the 48 conterminous states. Weighting for the 1989, 1990 and 1991 data sets was done in two stages. In the first phase a fundamental sampling weight (the inverse of the probability of selection) was computed and the responding weight (the inverse of the probability of selection) was computed for each responding household. This fundamental sampling weight was then adjusted to account for non-response at the area segment level. The second phase of computations used the weights produced in the first phase as the starting point of a reweighing process that used regression techniques to calibrate the sample to match characteristics thought to be correlated with eating behavior.

The weights used in this analysis reflect CSFII individuals providing intakes for three days. Weights for the 3-day individual intake sample were constructed separately for each of the three gender-age groups: males ages 20 and over, females ages 20 and over and persons aged less than 20 years. Characteristics used in weight construction included day of the week, month of the year, region, urbanization, income as a percent of poverty, food stamp use, home ownership, household composition, race, ethnicity and age of the individual. The individual's employment status for the previous week was used for persons ages 20 and older, and the employment status of the female head of household was used for individuals less than 20 years of age. The end result of this dual weighting process was to provide consumption estimates which are representative of the U.S. population.

Respondents were drawn from stratified area probability samples of noninstitutionalized U.S. households. Survey respondents were surveyed across all four seasons of the year, and data were obtained across all seven days of the week. The dietary assessment methodology consisted of assessment of three consecutive days of food intake, measured through one 24-hour-recall and two 1-day food records. For this analysis, the sample was limited to those individuals who provided records or recalls of three days of dietary intake.

For purposes of interpretability, it should be noted that assessment of fish consumption patterns by recall/record assessment methods will probably differ from assessments based on food frequency methods (See Section 4.1.2.3, below). In order to be designated a consumer or "user" of fish for purposes of the present analysis, an individual would need to have reported consumption of one or more fish/shellfish products at some time during the three days when dietary intake was assessed. Since fish is not a frequently consumed food for the majority of individuals, this dietary assessment method will likely underestimate the extent of fish consumption, because some individuals who normally consume fish will be missed if they did not consume fish during the three days of assessment. In contrast, such users would be picked up by a food frequency questionnaire. The recall/record dietary assessment method does have the advantage, however, of providing more precise estimates of the quantities of fish consumed that would be obtained with a food frequency record.

The information that follows comes from the CSFII 1989-1991 and was provided under contract to U.S. EPA by Dr. Pamela Haines of the Department of Nutrition of the University of North Carolina School of Public Health. Data are presented for following groups of individuals surveyed by USDA in the CSFII: data for the total population, data grouped by gender, and for data grouped by age-gender categories for the age groups 14 years or younger, 15 through 44 years, and 45 years and older (Table 4-5).

Fish consumption was defined to reflect consumption of approximately 250 individual "Fish only" food codes and approximately 165 "Mixed dish-fish" food codes present in the 1994 version of the USDA food composition tables. The USDA maintains a data base (called the "Recipe File") that describes all food ingredients that are part of a particular food. Through consultation with Dr. Betty Perloff, an USDA expert in the USDA recipe file, and Dr. Jacob Exler, an USDA expert in food composition, the USDA recipe file was searched for food codes containing fish or shellfish. The recipe was then scanned to determine fish codes that were present in the recipe reported as consumed by the survey respondent. The percent of the recipe that was fish by weight was determined by dividing the weight of the fish/shellfish in the dish by the total weight of the dish.

As with most dietary assessment studies, multiple days of intake were averaged to reflect usual dietary intake better. Intakes reported over the three-day period were summed and then divided by three to provide consumption estimates on a per person, per day basis.

Fish consumption was defined within the following categories.

1. *Fish and Shellfish*, all types reflected consumption of any fish food code.
2. *Marine Finfish*, included fish not further specified (e.g., tuna) and processed fish sticks, as well as anchovy, cod, croaker, eel, flounder, haddock, hake, herring, mackerel, mullet, ocean perch, pompano, porgy, ray, salmon, sardines, sea bass, skate, smelt, sturgeon, whiting.
3. *Marine Shellfish* included abalone, clams, crab, crayfish, lobster, mussels, oysters, scallops, shrimp and snails.
4. *Tuna*, contained only tuna.
5. *Shark, Barracuda, and Swordfish* contained just these three species of fish.
6. *Freshwater Fish* contained carp, catfish, perch, pike, trout and bass.

The analysis was stratified to reflect "per capita" (Table 4-12), as well as "per user" (Table 4-13), consumption patterns. A "consumer" of *Fish and Shellfish*, all types was one who consumed any of the included fish only or mixed-fish dish foods. A *Marine Finfish* consumer was one who consumed any of the species of fish included within the marine finfish category, and so on for each category. The percent of the population or subpopulation consuming fish was listed for the entire population, as well as gender specific values, and age-gender category specific values.

Table 4-12
Consumption of Fish and Shellfish (gms/day), and Self-Reported Body Weight (kg) in Respondents of the 1989-1991 CSFII Survey.
"Per Capita" Data for All Survey Respondents
(Data are weighted to be representative of the U.S. population.)

Gender	Aged 14 Years or Younger			Aged 15 through 44 Years			Aged 45 Years or Older			Total		
	Mean	SD	kg_{bw}	Mean	SD	kg_{bw}	Mean	SD	Kg_{bw}	Mean	SD	kg_{bw}
Males	9	20	26	19	35	73	20	36	90	17	33	68
Females	8	18	24	14	28	63	18	30	67	14	27	58

Table 4-13
Consumption of Fish and Shellfish (gms/day), and Self-Reported Body Weight (kg) in Respondents of the 1989-1991 CSFII Survey
(Data for "Users" Only. Data are weighted to be representative of the U.S. population.)

Gender	Aged 14 Years or Younger			Aged 15 through 44 Years			Aged 45 Years or Older			Total		
	Mean	SD	kg_{bw}	Mean	SD	kg_{bw}	Mean	SD	Kg_{bw}	Mean	SD	kg_{bw}
Males	32	27	28	54	39	80	51	42	83	49	39	59
Females	29	24	24	41	35	63	42	34	68	40	33	54

Consumption of fish-only and mixed-fish-dishes was summed across the three available days of dietary intake data. This sum was then divided by three to create average per day fish consumption figures. In the tables that describe fish intake, information is presented on sample size, percent of the population who consumed any product within the specified fish category, the mean grams consumed per day and the mean grams consumed per kilogram body weight (based on self-reported body weights), standard deviation, minimum, maximum, and the population intake levels at the 5th, 25th, 50th (median), 75th, and 95th percentiles of the intake distribution for each age-gender category. The means and standard deviations were determined using a SAS program. Survey sample weights were applied. Analysis with SAS does not take design effects into account, so the estimates of variance may differ from those obtained if SUDAAN or such packages had been used. It should be noted, however, that the point estimates of consumption (grams per consumer per day, grams per consumer per kilogram of body weight) will be exactly the same between the two statistical analysis packages. Thus, the point estimates reported are accurate and appropriate for interpretation on a national level.

Data were obtained for 11,706 individuals reporting 3-days of diet in the 1989-1991 CSFII survey. Analyses were based on data weighted through statistical procedures (as described previously) to be representative of the U.S. population. The total group of respondents reporting consumption of finfish and/or shellfish during the 3-day period were grouped as a subpopulation who consumed fish, as can be observed in Table 4-13. Fish and shellfish (total fish consumption) were reported to be eaten by 3614 persons (30.9%) of the 11,706 of the survey respondents (see Tables 4-12 and 4-13). The subpopulation considered to be of greatest interest in this Mercury Study: Report to Congress were women of child-bearing age (15 through 44 year-old females). Among this group of women ages 15 through 44 years, 864 women of the 2837 surveyed (30.5%) reported consuming fish (see Tables 4-12 and 4-13). Within this group, 334 women reported consumption of finfish during the 3-day survey period.

Consumption of fish and shellfish varied by species of fish. Overall, marine finfish (not including tuna, swordfish, barracuda, and shark) and tuna were consumed by more individuals and in greater quantity than were shellfish. Tuna fish was the most frequently consumed fish product, and separate tables are provided that identify quantity of tuna fish consumed. Two other categories of finfish were identified: freshwater fish and a category comprised of swordfish, barracuda, and shark. Freshwater fish were of interest because U.S. EPA's analysis of the fate and transport of ambient, anthropogenic mercury emissions from sources of concern in this report indicates that fish may bioaccumulate emitted mercury. Swordfish, barracuda, and shark were also identified as a separate category. These are predatory, highly migratory species that spend much of their lives at the high end of marine food web. These fish are large and accumulate higher concentrations of mercury than do lower trophic level, smaller fish.

4.1.2.2 Estimated Frequency of Fish/shellfish Consumption Based on Food Frequency Questions in CSFII 1994 and NHANES III

Both surveys included questions on frequency of consumption of fish and shellfish. The specific wording of the questions are shown in the box. The wording of CSFII 1994 separated canned fish from fish making it difficult to provide an overall estimate of fish consumption because no separate question addressed frequency of consumption of canned fish. The CSFII survey also provided a separate question on whether of not any of the fish the respondent ate was caught by the respondent or someone known to the respondent. Among those respondents who ate non-canned fish during the past 12-month period (84.1% of respondents), 37.5% indicated that they had consumed fish caught by themselves or a person known to them. Shellfish were reported to have been consumed by 62.2% of respondents during the past 12-month period.

Fish Consumption Survey Questions

CFSII 1994

During the past 12 months, that is, since last (NAME OF MONTH), (have you/has NAME) eaten any (FOOD) in any form?

	Yes	No
Shellfish	1	2
Fish, other than shellfish or canned fish	1	2
IF YES: Was any of the fish you ate caught by you or someone you know?	1	2

NHANES III

N2. MAIN DISHES, MEAT, FISH, CHICKEN, AND EGGS

	Times	Day	Week	Month	Never	or	DK
g. Shrimp, clams, oysters, crabs, and lobster	____ per	1□D	2□W	3□M	4□N	or	9□DK
h. Fish including fillets, fish sticks fish sandwiches, and tuna fish	___ per	1□D	2□W	3□M	4□N	or	9□DK

In the CSFII 1994 survey, subjects who consumed fish other than shellfish or canned fish were to select the answer "yes." Because canned fish (e.g., tuna, sardines) represent major food items, a portion of the fish consumers would indicate they were nonconsumers if they ate canned fish only. Consequently, using the results from the CSFII 1994 question would underestimate the frequency of consumption of fish.

NHANES III included two questions on fish and shellfish consumption as part of the household interview portion of the survey. The specific format and wording are shown below. Questions N2g and N2h addressed shrimp/shellfish and fish separately. Respondents were asked to indicate their frequency of consumption: never, or how often daily, weekly, or monthly they consumed shrimp/shellfish (g) or fish (h). Analyses of data from these questions provided the estimates of frequency of fish and shellfish consumption shown in Table 4-14.

Table 4-14
Frequency of Fish/Shellfish Ingestion and Percent of Respondents*
(NHANES III, Food Frequency Questionnaire, Weighted Data)

Number of times per month	All Adults	Women Aged 15 — 44 Years	Men Aged 15 —44 Years	Women Aged 45 Years and Older	Men Aged 45 Years and Older
0	12	14	11	11	9
1 or more	88	86	89	89	91
2 or more	79	78	81	80	83
4 or more	58	56	58	61	63
8 or more	23	25	29	30	31
12 or more	13	12	14	15	14
24 or more	3	3	3	2	3
30 or more	1	2	2	1	2

***Adult subjects only. Food frequency data were not collected for children ages 11 and younger.*

Frequency of fish and shellfish consumption data have also been calculated by ethnic/racial grouping. The groups were: Non-Hispanic whites ("Whites"), Non-Hispanic blacks ("Blacks") and persons designated as "Other" who included persons of Asian/Pacific Islander ethinicity, Native Americans, Non-Mexican Hispanics (predominately persons from Puerto Rica and other Carribean Islands), and additional groups not in the categories "Whites" or "Blacks". Food frequency data for these groups is shown in Tables 4-15 and 4-16.

Table 4-15a
Frequency of Fish and Shellfish Consumption by Percent among All Adults, Both Genders, Weighted Data, NHANES III*
(Estimated Frequency Per Month)

Frequency per Month	White	Black	Other
Zero	11.8	11.3	15.1
Once a Month or More	88.2	88.7	84.9
Once a Week or More	57.1	63.5	60.3
Twice a Week or More	25.9	31.9	31.2
Three-Times a Week or More	11.6	15.0	22.9
Approximately Daily (6 Times Per Week)	1.9	3.3	8.9

* *Adult subjects only. Food frequency data were not collected for children aged 11 years and younger.*

Table 4-15b
Frequency of Fish and Shellfish Consumption by Race/Ethnicity, Women Aged 15-44 Years, Weighted Data, NHANES III
(Estimated Frequency Per Month)

Frequency per Month	White	Black	Other
Zero	13.2	10.1	19.1
Once a Month or More	86.8	89.9	80.9
Once a Week or More	54.5	62.8	59.3
Twice a Week or More	22.0	31.7	35.6
Three-Times a Week or More	9.5	15.9	22.7
Approximately Daily (6 Times Per Week)	1.7	3.2	9.2

Table 4-16a
Distribution of the Frequency of Fish and Shellfish Consumption by Race/Ethnicity
All Adults, Both Genders, Weighted Data, NHANES III

Percentile	Whites	Blacks	Other
50th	4	4	5
75th	8	8	10
90th	13	13	22
95th	17	19	32

Table 4-16b
Distribution of the Frequency of Fish and Shellfish Consumption By Race/Ethnicity
Among Adult Women Aged 15-44, Weighted Data, NHANES III

Percentile	Whites	Blacks	Other
50th	4	4	5
75th	7	8	10
90th	11	14	23
95th	15	20	31

Overall 88% of all adults consume fish and shellfish at least once a month with 58% of adults consuming fish at least once a week. Between 13% and 23% consume fish/shellfish two or three times per week. An estimated 3% indicate they consume fish and shellfish six times a week with 1% of all respondents indicating they eat fish and shellfish daily. Comparatively small differences exist based on age and gender of adults. Two percent of women of reproductive age and 2% of men in the age range 15 through 44 years indicate they consume fish/shellfish daily.

Among diverse subpopulations those designated as “Other” consume fish and shellfish more frequently than do individuals in groups identified as “White” and “Black”. In the “Other” category 5% of individuals consume fish and shellfish daily (95th percentile value). Approximately 10% of the subpopulation of “Whites” consume fish and shellfish three-times or more per week with approximately 23% of persons in the “Other” classification consuming fish and shellfish three-times a week or more.

4.1.2.3 Frequency of Consumption of Various Fish Species by Respondents in NHANES III

Grouping of fish and shellfish species by habitat (i.e., freshwater, estuarine, and marine) was done based on an organization developed by US EPA’s Office of Water. Table 4-17 shows which species were grouped into these three habitat categories.

Table 4-17
Classification of Fish Species by Habitat*

Marine	Estuarine	Freshwater
Abalone	Anchovy	Carp
Barracuda	Clams (8%)	Catfish
Clams (92%)	Crab (46%)	Pike
Cod	Croaker	Salmon (1%)
Crab (54%)	Flatfish (29%)	Trout
Flatfish (71%)	Flounder	
Haddock	Herring	
Halibut	Mullet	
Lobster	Oyster	
Mackerel	Perch	
Mussels	Scallop (1%)	
Ocean Perch	Scup	
Octopus	Shrimp	
Pollock	Smelts	
Pompano	Sturgeon	
Porgy		
Salmon (99%)		
Sardine		
Scallop (99%)		
Sea Bass		
Seafood (e.g., fish sauce)		
Shark		
Snapper		
Swordfish		
Sole		
Squid		
Tuna		
Whitefish		
Whiting		

**Unprocessed fish (Food Codes 2815061 and 2815065) were not classified by habitat.*

Mean consumption rates for only males and females who reported consuming fish/shellfish in the NHANES III data set are shown in Table 4-18. Consumption rates for species grouped as marine, estuarine, and freshwater are shown in Table 4-19. Marine fish are the most frequently consumed followed by estuarine and freshwater fish. However, when freshwater fish are consumed the portion size is larger than for marine or estuarine fish. Males consumed larger portions of any of the fish groups than did female subjects.

Table 4-18
Weighted Estimates of Fish and Shellfish Consumed (gms) for Females and Males Aged 15 - 44 Years Reported in NHANES III (Per User)

Statistic	Females	Males
Mean	103	146
Standard Deviation	116	149
Minimum	1	1
Maximum	117	1097
Percentiles		
5th	12	14
10th	20	28
25th	37	51
Median	73	97
75th	131	185
90th	228	345
95th	288	435
Observations	883	645
Sum of Weights (000s)	1,162	9,223

Table 4-19
Weighted Estimates for Fish and Shellfish Consumed (gms) by Female and Male Respondents Aged 15 - 44 Years Reported in the NHANES III Survey by Habitat of Species Consumed

Statistic	Marine Fish		Estuarine Fish		Freshwater Fish	
	Females	Males	Females	Males	Females	Males
Mean	86	113	69	122	158	274
Std. Dev	86	122	64	131	138	268
Minimum	0	0	0	0	7	14
Maximum	957	1004	517	981	740	1097
Percentiles						
5th	8	1	8	5	13	42
10th	14	12	9	8	26	42
25th	37	44	22	29	50	123
Median	55	84	47	64	127	185
75th	109	153	101	175	235	313
90th	209	204	168	355	330	617
95th	247	351	202	357	330	929

Table 4-19 (continued)
Weighted Estimates for Fish and Shellfish Consumed (gms) by Female and Male Respondents Aged 15 - 44 Years Reported in the NHANES III Survey by Habitat of Species Consumed

Statistic	Marine Fish		Estuarine Fish		Freshwater Fish	
	Females	Males	Females	Males	Females	Males
Observations	519	387	221	198	82	60
Sum of Weights (000s)	6,457	5,999	2,653	2,477	516	588

4.1.3 Subpopulations with Potentially Higher Consumption Rates

The purpose of this section is to document fish consumption rates among U.S. subpopulations thought to have higher rates of fish consumption. These subpopulations include residents of the States of Alaska and Hawaii, Native American Tribes, Asian/Pacific Island ethnic groups, anglers, and children; these groups were selected for analysis because of potentially elevated fish consumption rates rather than because they were thought to have a high innate sensitivity to methylmercury. The presented estimates are the results of fish consumption surveys conducted on the specific populations. The surveys use several different techniques and illustrate a broad range of consumption rates among these subpopulations. In several studies the fish consumption rates of the subpopulations corroborate the high-end (90th percentile and above) fish consumption estimates of the the nationwide food consumption surveys.

Many of the surveys of fish consumption conducted on high-end fish consumers also included analyses for mercury in hair and blood of the people who were subjects. These data on biological monitoring provide an additional bases to estimate mercury exposure.

4.1.3.1 Subpopulations Included in Nationally Representative Food Consumption Surveys

Contemporary food consumption surveys designed to be representative of the U.S. population as a whole included identifiers for ethnically diverse subpopulations. Publicly available data from the NHANES III combined three subpopulations of interest with regard to level of fish consumption: Asian/Pacific origin, Native American origin, and others. By contrast, the CSFII 1994 and CSFII 1995 surveys provided separate estimates for identified ethnic subpopulations: white, black, Asian and Pacific Islander, Native American and Alaskan Native, and other (see Figure 4-1).

The 50th, 90th and 95th percentiles for all survey participants in CSFII 1994 and CSFII 1995 for "Day 1" and "Day 2" recall data are shown in Table 4-20. The number of 24-hour recall food consumption reports for each group is noted in the table food note. Data are presented for both "per capita" and "per user." The subpopulation self-designated as "white" has the smallest intake of fish/shellfish and mercury at the 50th percentile. "Blacks" have higher levels of intake and Asian and Pacific Islanders have the highest intake of fish/shellfish. Similar patterns are observed at the 90th and 95th percentile.

If the data are calculated for only those persons who reported consuming fish and shellfish, a somewhat different pattern emerges. A median intake of fish/shellfish is the lowest among Asian and Pacific Islanders, intermediate among "whites" and highest among "blacks." The number of observations among Native Americans and Alaska Natives are too small to produce reliable estimates.

Figure 4-1
Distribution of Fish Consumption Rates of Various Populations

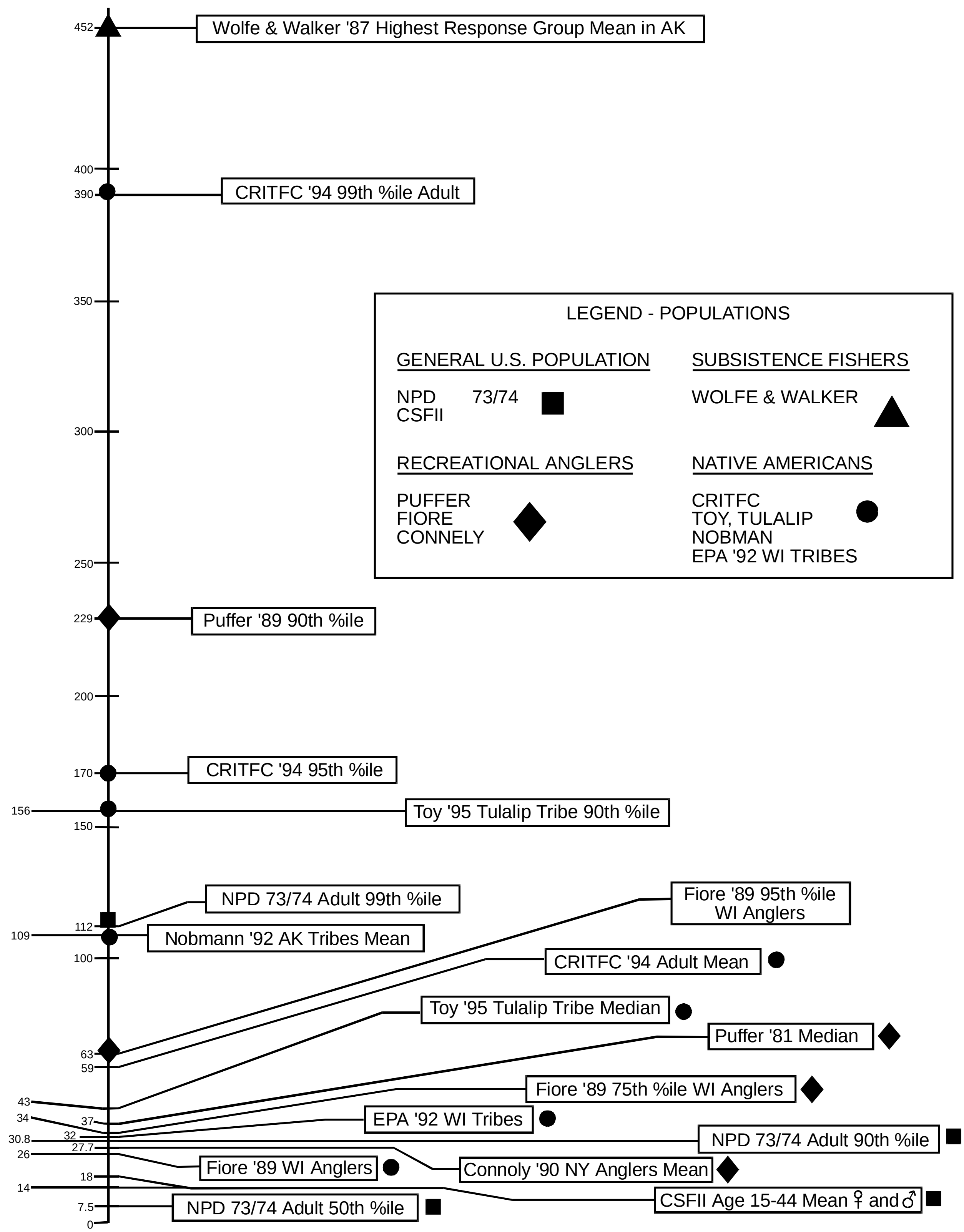

Table 4-20
Consumption of Fish and Shellfish (gms/day) among Ethnically Diverse Groups
(Source: CSFII 1994 and CSFII 1995)

Ethnic Group	**Fish Consumption *(grams/day)***	
	***Per Capita*[1]**	***Per User*[2]**
White		
50th Percentile	Zero	72
90th Percentile	24	192
95th Percentile	80	243
Black		
50th Percentile	Zero	82
90th Percentile	48	228
95th Percentile	104	302
Asian and Pacific Islander		
50th Percentile	Zero	62
90th Percentile	80	189
95th Percentile	127	292
Native American and Alaska Native		
50th Percentile	Zero	*Estimate not made because of small numbers of respondents.*
90th Percentile	Zero	
95th Percentile	56	
Other		
50th Percentile	Zero	83
90th Percentile	Zero	294
95th Percentile	62	327

[1]*Total number of 24-hour food consumption recall reports: White (16,241); Black (2,580); Asian and Pacific Islander (532); Native American and Alaska Native (166): and Other (1,195).*
[2] *Number of 24-hour food consumption recall reports: White (1,821); Black (329); Asian and Pacific Islander (155); Native American and Alaska Native (12); and Other (98).*

4.1.3.2 Specialized Surveys

During the past decade, data describing the quantities of fish consumed by angler, economically subsistent, and North American Tribal groups have been published (Tables 4-23 and 4-30). Subpopulations of particular concern because of exposure patterns are Native Americans, sport anglers, the urban poor, and children. Data on fish consumption for these groups indicate that exposures for these subgroups exceed those of the general population of adults. If North American data, including those from Canada, are considered, mercury exposures from the marine food web (especially if marine mammals are consumed) exceed limits such as the Tolerable Daily Intake established by Health Canada (Chan, 1997) and the Acceptable Daily Intake established by the U.S. Food and Drug Administration.

The data cited below on specific subpopulations are not utilized in this Report as the basis of a site-specific assessment. In a site-specific assessment the fish consumption rates among a surveyed population would be combined with specific measurements of methylmercury concentrations in the local fish actually consumed to estimate the human contact rate. Ideally, some follow-up analysis such as concentrations of mercury in human blood or hair would ensue.

Analytic and survey methods to estimate the fish consumption rates of the respondents are described for each population. This chapter does not constitute an exhaustive review of the methods employed. An attempt was made to characterize the population surveyed. Additionally, to characterize the entire range of fish consumption rates in the surveyed populations, the consumption rates of both average and high-end consumers as well as other specific angler subpopulations (e.g., fish consumption by angler race or age) are presented.

The sources of consumed fish are also identified in the summaries. Fish consumed by humans can be derived from many sources; these include self-caught, gift, as well as grocery and restaurant purchases. Some studies describe only the consumption rates for self-caught fish or freshwater fish, others estimate total fish consumption, and some delineate each source of fish. Humans also consume fish from many different types of water bodies. When described by the reporting authors, these are also identified.

Assumptions concerning fish consumption made by the study authors are also identified. Humans generally do not eat the entire fish; however, the species and body parts of fish which are consumed may be highly variable among angler populations (for example, see Toy et al. 1995). Anglers do not eat their entire catch, and, some species of fish are typically not eaten by specific angling subpopulations. For example, Ebert et al. (1993) noted that some types and parts of harvested fish are used as bait, fed to pets or simply discarded. Study authors account for the differences between catch weight and number in a variety of different ways. Typically, a consumption factor was applied. These assumptions impact the author's consumption rate estimates.

Data from angler and indigenous populations are useful in that they corroborate the ranges identified in the 3-day fish consumption data. The data are not utilized in this Report as the basis of a site-specific assessment. In a site-specific assessment the fish consumption rates among a surveyed population would be combined with specific measurements of methylmercury concentrations in the local fish actually consumed to estimate the human contact rate. Ideally, some follow-up analysis such as concentrations in human blood or hair would ensue.

4.1.3.3 U.S. Subsistent Populations

Large urban populations include individuals who obtain some of their food by catching and eating fish from local urban waters. For example, Waller et al. (1996) identified populations living along the lake shore of Chicago who have ready access to fishing waters of Lake Michigan along the break waters, the harbors, and in the park lagoons adjacent to Lake Michigan (Table 4-21). Similar situations occur for many water bodies in urban areas throughout the United States.

Table 4-21
Fish Consumption of an Urban "Subsistent" Group

Study	Description of Group	Fish Consumption Pattern	Notes
Waller et al., 1996	484 pregnant African-American, urban poor women	45 of 444 ate no fish; 46 of 444 consumed sport-caught fish; 34 of the women who consumed sport-caught fish also consumed store-bought fish.	Types of fish eaten most frequently in descending order: catfish, perch, buffalo, silver bass, and whiting. Others included: bull heads, sunfish, bluegills, and crappie. Most catfish consumed was store-bought. Generally fisheaters did not consume only one type of fish. Most of the individuals eating sport-caught fish also ate wild fowl and other game (duck, raccoon, opossum, squirrel, turkey, goose, and other fowl.

Another group of urban consumers who subsist on fish are persons who are not limited in income, but individuals who choose to consume a large proportion of their dietary protein from fish because of taste preference or pursuit of health benefits attributed to fish. For an undetermined number of these individuals, a particular species of fish may be preferred (e.g., swordfish, sea bass, etc.) and consumed extensively. Depending on the mercury concentration of the preferred fish, the result of consuming diets high in fish from one source can be substantially increased exposure to mercury. For example, Knobeloch et al. (1996) provide cases reports of a family whose blood mercury concentrations increased about ten-fold following long-term consumption of a particular commercial source of imported fish (Table 4-22). Likewise, investigation by state authorities in Maine of elevated blood mercury concentrations thought to result from occupational exposures to mercury, in fact, resulted from frequent consumption of fish (Dr. Allison Hawkes, 1997). After following physician's advise to reduce fish consumption the blood mercury levels decreased.

Table 4-22
High Fish Consumption among Urban Subjects: Case Report

Study	Description of Group	Fish Consumption Pattern	Notes
Knobeloch et al., 1995	Family consuming commercially available fish.	Wisconsin family consumed two meals/week of seabass imported from Chile and obtained commercially which had a mercury concentration between 0.5 and 0.7 µg/g. Other fish having low mercury concentrations (<0.05 µg/g) were also consumed. The father consumed an average of 113 g of fish/day, the mother and son consumed approximately 75 and 37 grams of fish/day, respectively. Calculated mercury intakes ranged from 9 µg/day (young child) to 52 µg/day for the father in the household.	Family members had blood mercury levels elevated to 37 and 58 µg/L and hair mercury values of 10 and 12 µg/g. Cessation of fish consumption for 200 days reduced blood mercury levels to 3 and 5 µg/L.

4.1.3.4 U.S. Immigrant Populations

Subpopulations of recent immigrants to the United States retain food patterns characteristic of their cultures with adaptations based on the available food supply. In the 1980s and 1990s, the proportion of the U.S. population whose ancestry was Southeast Asian or Caribbean origin increased. The people of rural Cambodia, Laos, and Vietnam supplemented their agricultural resources by hunting and fishing (Shubat et al., 1996) and many continue to do so in the United States. Puffer (1981) found that Oriental/Samoan recreational anglers had fish consumption rates twice the mean value for all anglers in the survey. Specialized fish advisories for chemical contaminants and outreach programs for Southeast Asian communities have been developed (Shubat et al., 1996). Increased consumption of purchased frozen fish, as well as self-caught fish, among Southeast Asians has been reported (Shatenstein et al., 1997). Overall, these subpopulations have higher fish consumption than does the general U.S. population.

4.1.3.5 U.S. Angling Population Size Estimate and Behaviors

Many citizens catch and consume fish from U.S. waters. The U.S. Fish and Wildlife Service (U.S. FWS, 1988) reported that in 1985, 26% of the U.S. population fished; over 46 million people in the U.S. spent time fishing during 1985. Within the U.S. population fishing rates ranged from a low of 17% for the population in the Middle Atlantic states up to 36% in the West North Central States. These angling subpopulations included both licensed and non-licensed fishers, hook and line anglers as well as those who utilized special angling techniques (e.g., bow and arrows, spears or ice-fishing).

U.S. FWS (1988) also noted the harvest and consumption of fish from water bodies where fishing is prohibited. This disregard or ignorance of fish advisories is corroborated in other U.S. angler surveys. For example, Fiore et al. (1989) noted that 72% of the respondents in a Wisconsin angler survey were familiar with the State of Wisconsin Fish Consumption Health Advisory, and 57% of the respondents reported changing their fishing or fish consumption habits based on the advisory. West et al. (1989) noted that 87.3% of respondents were "aware or generally aware" of Michigan State's fish consumption advisories. Finally, Connelly et al. (1990) reported that 82% of respondents knew about the New York State fish health advisories. They also noted a specific example in which angler consumption exceeded an advisory. The State of New York State recommends the consumption of no more than 12 fish meals/year of contaminated Lake Ontario fish species; yet, 15% of the anglers, who fished this lake, reported eating more than 12 fish meals of the contaminated species from the lake in that year.

The extent of the angling population can also be judged from a question included in the USDA’s CSFII for the years 1994 and 1995. In response to a question of whether or not they had eaten fish within the past 12 months, 84% of individuals indicated they had. Of those who had eaten fish, 38% indicated that the fish they had eaten was caught by themselves or someone known to the respondent.

4.1.3.6 U.S. Angler Surveys

Summary of Angler Surveys

The results of the fish consumption surveys are compiled in Table 4-23. These results illustrate the range of fish consumption rates identified in angler consumption surveys. There is a broad range of fish consumption rates reported for angling populations. The range extends from 2 g/day to greater than 200 g/day. The variability is the result of differences in the study designs and purposes as well as differences in the populations surveyed.

Table 4-23
Compilation of the Angler Consumption Studies

Source	Population	Percentile	Daily Fish Consumption g/day	Notes
Soldat, 1970	Columbia River Anglers	Mean	2	Estimate of average finfish consumption from river.
Puffer, 1981; as cited in U.S. EPA, 1990	Los Angeles area coastal anglers	Median 90th Percentile <u>Ethnic Subpopulation Medians</u> African-American Caucasian Mexican-American Oriental/Samoan	37 225 24 46 33 71	Estimates for anglers and family members who consume their catch. Consumption rate includes ingestion of both finfish and shellfish.
Pierce et al., 1981; as cited in EPA, 1990	Commence-ment Bay in Tacoma, WA	50th Percentile 90th Percentile Maximum Reported	23 54 381	Finfish only
Fiore et al., 1989	Licensed WI Anglers	Mean 75th Percentile 95th Percentile	12 16 37	Fish-Eaters, Daily Sportfish Intake
		Mean 75th Percentile 95th Percentile	26 34 63	Fish-Eaters, Total Fish Intake
West et al., 1989	Licensed MI Anglers	Mean Mean for Minorities Maximum Reported	19 22 >200	Daily Sportfish Intake
West et al., 1993	Licensed MI Anglers	Mean	15 43	Daily sportfish intake
Turcotte, 1983	GA anglers	Child Teenager Average Angler Maximum Angler	10 23 31 58	Estimates of Freshwater Fish Intake from the Savannah River
Hovinga et al., 1992 and 1993	Caucasians living along Lake Michigan	Maximum Reported	132	Re-examination of Previously Identified High-End Fish Consuming Population
Ebert et al., 1993	ME anglers licensed to fish inland waters	Mean 50th Percentile 75th Percentile 90th Percentile 95th Percentile	6 2 6 13 26	Sportfish Intake

Table 4-23 (continued)
Compilation of the Angler Consumption Studies

Source	Population	Percentile	Daily Fish Consumption g/day	Notes
Courval et al., 1996	Data on 1,950 question-naires from Michigan anglers aged 18-34 years.		46% of respondents reported eating sport-caught fish 1-12 times: 20% reported eating no sport-caught fish; 20% consumed 13 to 24 meals. Approximately 10% consumed 25 to more than 49 meals/month.	Approximately 30% of female respondents consumed no sport-caught fish - about double that of male respondents. In the 1 to 12 meal/month range males and females about equally represented. More than 13 meals/month exposure category had a higher proportion of males.
Meredith and Malvestuto, 1996	29 locations in Alabama. Seasonal estimates of freshwater fish consumption		Compared harvest method and serving-size methods of estimating consumption. Harvest method yielded estimates of 43 grams/day fish consumed from all sites in Alabama (number = 563). Serving-size method estimates 46 grams/day from all sites in Alabama (number = 1311) Consumption lowest in the Spring	Survey to determine consumption rates of anglers yielded comparable estimates of grams/day consumed. However, serving size method yielded four-times as many consumers.

Table 4-23 (continued)
Compilation of the Angler Consumption Studies

Source	Population	Percentile	Daily Fish Consumption g/day	Notes
Shubat et al., 1996	30 Hmong anglers (residents of St. Paul and Minneapolis) fishing St. Croix or Mississippi Rivers. Ages 17-88.		Respondents ate an average of 3.3±3.0 fish meals per month (range 0.5 to 12). Median 2 meals per month and 8.8 meals at 90th percentile.	Consumption of caught fish only. No information about size of meals. Species most frequently caught: crappie, white bass and walleye, other bass (largemouth and smallmouth), northern pike, trout, bluegill and catfish.
Sekerke et al., 1994	FL residents receiving foodstamps	Male Mean Female Mean	60 40	Total Home Fish Consumption

Anglers of the Columbia River, Washington

Soldat (1970) measured fishing activity along the Columbia River during the daylight hours of one calendar year (1967-68). The average angler in the sampled population made 4.7 fishing trips per year and caught an average of 1 fish per trip. Assuming 200 g of fish consumed per meal, Soldat estimated an average of 0.7 fish meals were harvested per trip; this results in an average of 3.3 Columbia River fish meals/year. The product of 3.3 meals/year and 200 g/meal is 660 g/year; an estimate of 1.8 g/day results. While not reporting the high-end harvesting or consumption rates, Soldat reported that approximately 15% of the 1400 anglers interviewed caught 90% of the fish.

Los Angeles, California Anglers

The results of studies from Puffer (1981) and Pierce et al. (1981) are described in U.S. EPA (1989). Puffer (1981) conducted 1,059 interviews with anglers in the coastal Los Angeles area for an entire year. Consumption rates were estimated for anglers who ate their catch. These estimates were based on angling frequency and the assumption of equal fish consumption among all fish-eating family members. The median consumption rate for fish and shellfish was 37 g/day. The 90th percentile was 224.8 g/day. Table 4-24 notes the higher consumption rate estimates among Orientals and Samoans.

Table 4-24
Median Recreationally Caught Fish Consumption Rate Estimates by Ethnic Group (Puffer, 1981)

Ethnic Group	Median Consumption Rate (g/day)
African-American	24
Caucasian	46
Mexican-American	33
Oriental/Samoan	71
Total	**37**

Anglers of the Commencement Bay Area in Tacoma, Washington

Pierce et al. (1981), as reported in the U.S. EPA 1990 Exposure Factors Handbook, conducted a total of 509 interviews in the summer and fall around Commencement Bay in Tacoma, Washington. They assumed that 49% of the live fish weight was edible and that 98% of the total catch was eaten. The estimated 50th percentile consumption rate was 23 g/day and the estimated 90th percentile consumption rate 54 g/day. The maximum estimated consumption rate was 381 g/day based on daily angling.

Anglers of the Savannah River in Georgia

Turcotte (1983) estimated fish consumption from the Savannah River based on total harvest, population studies and a Georgia fishery survey (Table 4-25). The angler survey data, which included the number of fishing trips per year as well as the number and weights of fish harvested per trip, were used to estimate the average consumption rate in the angler population. Several techniques including the use of the angler survey data were used to estimate the maximum fish consumption in the angler population. Estimates of average fish consumption for children and teens was also provided.

Table 4-25
Freshwater Fish Consumption Estimates of Turcotte (1983)

Georgia Subpopulation	Estimated Freshwater Fish Consumption Rate (g/day)
Child	10
Teen-ager	23
Average Angler	31
Maximum Angler	58

Alabama Anglers

Meredith and Malestuto (1996) studied anglers in 29 locations in Alabama to estimate freshwater fish consumption (Table 4-23). The purpose of their study had been to compare two methods of estimating fish consumption: The harvest or krill survey compared with the serving-size method of estimating fish consumption. These two techniques yielded comparable estimates of mean fish intake (43 and 46 gms/person/day, respectively). The serving size method identified 1311 consumers while the harvest method identified only 563 consumers.

Wisconsin Anglers

Fiore et al. (1989) surveyed the fishing and fish consumption habits of 801 licensed Wisconsin anglers. The respondents were divided into 2 groups: fish eaters and non-eaters. The fish eaters group was further subdivided into four groups: those who consumed 0-1.8 kg fish/yr, 1.9-4.5 kg fish/yr, 4.6-10.9 kg fish/yr and 10.9 < kg fish/yr. Using an assumption of 8 oz. (227 grams) fish consumed/meal, the authors estimated that the mean number of sport fish meals/year for all respondents (including non-eaters) was 18. The mean number of other fish meals/year including non-eaters was 24. The total number of fish meals/year was 41 for fish eaters and non-eaters combined and 42 for fish eaters only. Recreational anglers were found to consume both commercial fish as well as sport fish. The estimated daily consumption rates of the eaters-only are presented in Table 4-26.

Table 4-26
Daily Intake of Sportfish and Total Fish for the Fish-consuming Portion of the Population Studied by Fiore et al. (1989)

Percentile	Daily Sport-Fish Intake	Daily Total Fish Intake
Mean	12 g/day	26 g/day
75th	16 g/day	34 g/day
95th	37 g/day	63 g/day

Michigan Anglers

West et al. (1989) used a mail survey to conduct a 7-day fish consumption recall study for licensed Michigan anglers. The respondents numbered 1104, and the response rate was 47.3%. The mean fish consumption rate for anglers and other fish-eating members of their households was 18.3 g/day, and the standard deviation was 26.8 g. Because the study was conducted from January through June, an off-season for some forms of angling in Michigan, higher rates of fish consumption would be expected during the summer and fall months. A full-year's mean fish consumption rate of 19.2 g/day was estimated from seasonal data. The mean fish consumption rate for minorities was estimated to be 21.7 g/day. The highest consumption rates reported were over 200 g/day; this occurred in 0.1% of the population surveyed. Overall, fish consumption rates increased with angler age and lower education levels. Lower income and education level groups were found to be the only group which consumed bottom-feeders.

New York State Anglers

Connelly et al. (1990) reported the results of a statewide survey of New York anglers. The 10,314 respondents (62.4% response rate) reported a mean of 20.5 days spent fishing/year. Of the respondents, 84% fished the inland waters of New York State, and 42% reported fishing in the Great Lakes. An overall mean of 45.2 fish meals per year was determined for New York anglers. The authors assumed an average meal size of 8 oz. (227 g) of fish and estimated a yearly consumption rate of 10.1 kg fish (27.7 g fish/day). Unlike the Michigan angler study (West et al., 1989), the overall mean number of fish meals consumed increased with education level of the angler. Fish consumption also increased with increasing income; respondents earning more than $50,000/year consumed a mean of 54.3 meals per year, and those with some post-graduate education consumed a mean of 56.2 meals per year. The highest reported regional mean consumption rates (58.8 meals/year) occurred in the Suffolk and Nassau Counties of New York State.

Anglers of Lake Michigan

As part of a larger effort, Hovinga et al. (1992 and 1993) re-examined 115 eaters of Great Lakes fish and 127 controls, who consumed smaller quantities of fish, originally identified in a 1982 effort. Both more recent (1989) as well as 1982 consumption rates of Great Lakes sportfish were estimated. All of the participants in the study were Caucasian and resided in 11 communities along Lake Michigan. The population was divided into eaters (defined as individuals consuming 10.9 kg (30 g/day) or greater) and controls (defined as individuals consuming no more than 2.72 kg/yr). The consumption rates for the groups are reported in Table 4-27.

Table 4-27
Fish Consumption Rate Data for Groups Identified in Hovinga et al. (1992) as Eaters and Controls

Groups	1982 Meals/Year Mean (Range)	1982 Consumption Rates (kg/yr) Mean (Range)	1989 Meals/Year Mean (Range)	1989 Consumption Rates (kg/yr) Mean (Range)
Eaters	54 (24-132)	18 (11-53)	38 (0-108)	10 (0-48)
Controls	--	--	4.1 (0-52)	0.73 (0-8.8)

Anglers of Inland Waters in the State of Maine

Ebert et al. (1993) examined freshwater fish consumption rates of 1,612 anglers licensed to fish the inland (fresh) waters of Maine. They only analyzed fish caught and eaten by the anglers. Anglers were asked to recall the number, species and average length of fish eaten in the previous year; the actual fish consumption rates were estimated based on an estimate of edible portion of the fish. The 78% of respondents who fished in the previous year and 7% who did not fish but did consume freshwater fish were combined for the analysis. Anglers who practiced ice-fishing as well as fish caught in both standing and flowing waters were included. Twenty-three percent of the anglers consumed no freshwater fish. If the authors assumed that the fish were shared evenly among all fish consumers in the angler's family, a mean consumption rate of 3.7 g/day was estimated for each consumer. Table 4-28 provides the fish consumption rates for Maine anglers.

Table 4-28
Fish Consumption Rates for Maine Anglers

Percentile	All Anglers	Fish-consuming Anglers
Mean	5.0	6.4
50th (median)	1.1	2.0
75th	4.2	5.8
90th	11	13
95th	21	26

Florida Anglers Who Receive Food Stamps

As part of a larger effort the Florida Department of Environmental Regulation attempted to identify fish consumption rates of anglers who were thought to consume higher rates of fish. Face-to-face interviews were conducted at five Florida food stamp distribution centers. The selected food stamp distribution centers were located in counties either thought to have a high likelihood of subsistence anglers or where pollutant concentrations in fish were known. Interviews with twenty-five household's primary seafood preparer were conducted at each center per quarter for an entire year. A total of 500 interviews was collected. The interviewed were asked to recall fish consumption within the last 7 days. Specifically, the respondents were asked to recall the species, sources and quantities of fish consumed. Note that the respondents were only asked to recall fish meals prepared at home (actual consumption rates may have been higher if the respondents consumed seafood elsewhere) and that the sources of fish were from both salt and freshwater. The results of the survey conducted by Sekerke et al. (1994) are in Table 4-29.

Table 4-29
Fish Consumption Rates of Florida Anglers Who Receive Food Stamps

Respondent	No.	Average Finfish Consumption	Average Shellfish Consumption
Adult Males	366	60 g/day	50 g/day
Adult Females	596	40 g/day	30 g/day

4.1.3.7 Indigenous Populations of the United States

The tribes and ethnic groups who comprise the indigenous populations of the United States show wide variability in fish consumption patterns. Although some tribes, such as the Navajo, consume minimal amounts of fish as part of their traditional culture, other native groups — such as the Eskimos, Indians, and Aleuts of Alaska, or the tribes of Puget Sound — traditionally consume high quantities of fish and fish products. The U.S. indigenous populations are widely distributed geographically. For example, a U.S. EPA report (1992b) identified 281 Federal Indian reservations that cover 54 million acres in the United States. Treaty rights to graze livestock, hunt, and fish are held by native peoples for an additional 100 to 125 million acres. There are an estimated two million American Indians in the

United States (U.S. EPA, 1992b). Forty-five percent of these two million native people live on or near reservations and trust lands. High-end fish consuming groups include Alaska natives who number between 85,000 and 86,000 people (Nobmann et al., 1992).

Fish products consumed by indigenous populations may rely on preparation methods that differ from ones typically encountered in the diet of the general U.S. population. By way of illustration, food intake data obtained from Alaskan natives were used to calculate nutrient intakes using a computer and software program. These computerized databases had been developed by the U.S. Veterans Administration (VA) for patients in the national Veteran's Administration hospital system. Nobmann et al. (1992) found they needed to add data for 210 dietary items consumed by Alaskan Natives to the 2400 food items in the VA files.

In the mid-1990s data on fish consumption by indigenous populations of the United States were reported for Alaska Natives (Nobmann et al., 1992), Wisconsin Tribes (U.S. EPA, 1992), the Columbia River Tribes (Columbia River Inter-Tribal Fish Commission, 1994) and selected Puget Sound Tribes (Toy et al. 1995). Findings from these studies can be used to assess differences in fish consumption between these indigenous groups and the general U.S. population.

Summary of Native American Angler Surveys

Table 4-30 summarizes the reported consumption rates of Native Americans detailed here. Although not all Native American tribal groups traditionally include fish as part of their diets, groups living near rivers, lakes, and coastal areas consume a vide variety of fish and shellfish. The highest levels of fish and shellfish consumption are thought to occur among tribal groups living along the Pacific Coast and in Alaska. Tribal groups in the Great Lakes region also include fish as part of their typical diet. The data base to estimate quantities of fish consumed has been greatly enhanced over the past five years with the publication of a number of dietary assessments conducted as part of activities to determine exposure to chemical contaminants in fish.

Surveys of Native American anglers in the United States indicate an average fish/shellfish consumption in the rage of 30 to 80 grams per day (U.S. EPA, 1992b; Harnly et al., 1997; Toy et al., 1995) with 90th percentile consumption of about 150 grams/day or higher (Toy et al., 1995). Inclusion of data on Alaskan Native Americans results in still higher levels of fish and shellfish intake. For example, Nobmann et al. (1992) reported mean fish consumption estimates in excess of 100 grams/day.

Table 4-30
Fish Consumption by Native U.S. Populations

Source	Population	Percentile	Fish-Meals Consumed or Fish Consumption (gms)	Notes
Nobmann et al., 1992	351 Alaska Native adults (Eskimos, Indians, Aleuts)	Mean	109 gms of fish and shellfish per day.	
U.S. EPA, 1992b	Wisconsin Tribes 11 Native American Indian Tribes	Mean	32 gms of fish per day	

Table 4-30 (continued)
Fish Consumption by Native U.S. Populations

Source	Population	Percentile	Fish-Meals Consumed or Fish Consumption (gms)	Notes
Peterson et al., 1995	323 Chippewa adults > 18 years of age.	Mean = 1.7 fish meals/week. (1.9 and 1.5 fish meals/week for male and for female respondents, respectively). 0.26% of males and 0.15% of females reported eating 3 or more fish-meals per week. 50% of respondents ate one or less fish meals per week. 21% of respondents ate three or more fish meals per week. 2% of respondents ate fish-meals each day.		
Toy et al., 1995	Tulalip and Squaxin Island Tribes. 263 adult subjects.	*50th percentile:* Finfish, 22 gms/day; total fish consumed, 43 gms/day. *90th percentile:* Finfish, 88 gms/day; total fish, 156 gms/day.		Report contains data for anadromous fish, pelagic, bottom and shell fish. Data are based on an average body weight of 70 kg/day.
Fitzgerald et al., 1995	97 nursing Mohawk women	24.7% ate 1-9 local fish meals/year during pregnancy; 10.3% ate >9 local fish meals/year during pregnancy; 41.2% ate 1-9 local fish meals/year one year prior to pregnancy; 15.4% ate >9 local fish meals/year one year prior to pregnancy;		Study conducted from 1986-1992 in area where fish are contaminated with PCB

Table 4-30 (continued)
Fish Consumption by Native U.S. Populations

Source	Population	Percentile	Fish-Meals Consumed or Fish Consumption (gms)	Notes
Centers for Disease Control, 1993	Miccouskee Indian Tribes of South Florida (1993), 2 children and 183 adults completed dietary questionaires		Local fish: 31% (58 persons) reported eating fish from Everglades during previous 6 months. Maximum daily consumption: 168 grams Median daily consumption: 3.5 grams Marine fish: 57% (105 persons) consumed marine fish during previous 6 months. Nonlocal freshwater fish: 1 individual, 25 grams/day Local wildlife: 65% (120 participants) consumed local game.	Blue gill most common species of local fish consumed. Largemouth bass consumed in greatest quantity Canned tuna most commonly consumed (by all 105 of marine consumers) and in the largest amounts (7.0 grams/day median level) Local game consumed: deer (57% of participants), wildboar (10%), redbelly turtle (10%), frog (5%) and alligator (3%)
Gerstenberger et al., 1997	89 Ojibwa Tribal members from the Great Lakes Region		35% of respondents ate Lake Superior fish 1x/week. 6.7% ate Lake Superior fish 2x/week. Consumption of fish from other lakes: 12.5% ate these 1x/week 5.7% ate these 2x/week 89 respondents averaged 29 fish meals/year (range zero to 150 fish meals/year)	Most frequently consumed fish from Lake Superior: lake trout (37%), walleye (27%), whitefish (27%). From inland lakes: Walleye. Highest fish consumption in April, May, and June

Table 4-30 (continued)
Fish Consumption by Native U.S. Populations

Source	Population	Percentile	Fish-Meals Consumed or Fish Consumption (gms)	Notes
Harnly et al., 1997	Native Americans living near Clear Lake California		Fish-consuming participants averaged 60 g/day of sportfish and 24 g/day of commercial fish. 10% of adults consumed Hg intakes > 30 µg/day	Sportfish species: catfish, perch, hitch, bass, carp Commercial fish: snapper, tuna, salmon, crab, shrimp.

Wisconsin Tribes

An U.S. EPA report entitled *Tribes at Risk* (The Wisconsin Tribes Comparative Risk Project) (US EPA, 1992) reported an average total daily fish intake for Native Americans living in Wisconsin of 35 gms/day. The average daily intake of locally harvested fish was 31.5 grams.

Peterson et al. (1995) surveyed 323 Chippewa adults over 18 years of age living on the Chippewa reservation in Wisconsin. The survey was conducted by interview and included questions about season, species and source of fish consumed. The survey was carried out in May. Fish consumption was found to be seasonal with the highest fish consumption occurring in April and May. Fish species typically consumed were walleye and northern pike, muskellunge and bass. During the months in which the Chippewa ate the most fish, 50% of respondents reported eating one or fewer fish meals per week, 21% reported eating three or more fish meals per week, and 2% reported daily fish consumption. The mean number of fish meals per week during the peak consumption period was 1.7 meals; this is approximately 42% higher than the 1.2 fish meals per week that respondents reported as their usual fish consumption. Higher levels of fish consumption were reported by males (1.9 meals per week) than by females (1.5 meals per week). Among male respondents 0.26% ate 3 or more fish meals per week, whereas 0.15% of female respondents ate 3 or more meals of fish per week. Unemployed persons typically had higher fish consumption rates.

Columbia River Tribes

The Columbia River Inter-Tribal Fish Commission (1994) estimated fish consumption rates based on interviews with 513 adult tribal members of four tribes inhabiting the Columbia River Basin (see Tables 4-31 and 4-32). The participants had been selected from patient registration lists provided by the Indian Health Service. Data on fish consumption by 204 children under 5 years of age were obtained by interviewing the adults.

Fish were consumed by over 90% of the population with only 9% of the respondents reporting no fish consumption. The average daily consumption rate during the two highest intake months was 108 grams/day, and the daily consumption rate during the two highest and lowest intake months were 108 g/day and 31 g/day, respectively. Members who were aged 60 years and older had an average daily consumption rate of 74 grams/day. During the past two decades, a decrease in fish consumption was generally noted among respondents in this survey. The maximum daily consumption rate for fish reported for this group was approximately 970 grams/day.

Table 4-31
Fish Consumption by Columbia River Tribes
(Columbia River Inter-Tribal Commission, 1994)

Subpopulation	Mean Daily Fish Consumption (g/day)
Total Adult Population, aged 18 years and older	59
Children, aged 5 years and younger	20
Adult Females	56
Adult Males	63

Table 4-32
Daily Fish Consumption Rates by Adults of Columbia River Tribes
(Columbia River Inter-Tribal Commission, 1994)

Percentile	Amount (g/day)
50th	29-32
90th	97-130
95th	170
99th	389

Tribes of Puget Sound

A study of fish consumption among the Tulalip and Squaxin Island Tribes of Puget Sound was completed in November 1994 (Toy et al., 1995). The Tulalip and Squaxin Island Tribes live predominantly on reservations near Puget Sound, Washington. Both tribes rely on commercial fishing as an important part of tribal income. Subsistence fishing and shell-fishing are significant parts of tribal members economies and diets.

The study was conducted between February and April in 1994. Fish consumption practices were assessed by questionnaire and interview using dietary recall methods, food models and a food frequency questionnaire. The food frequency questionnaire was aimed as identifying seasonal variability. Questions in the interview included food preparation methods and obtained information on the parts of the fish consumed. Fish consumed were categorized into anadromous fish (king salmon, sockeye salmon, coho salmon, chum salmon, pink salmon, steelhead salmon, salmon unidentified and smelt); pelagic fish (cod, pollock, sable fish, spiny dogfish, rockfish, greenling, herring and perch); bottom fish (halibut, sole/flounder and sturgeon); and shell fish (manila clams, little clams, horse clams, butter clams, cockles, oysters, mussels, shrimp, dungeness crab, red rock crab, scallops, squid, sea urchin, sea cucumbers and moon snails).

Among consumers of anadromous fish, local waters (i.e., Puget Sound) supplied a mean of 80% of the fish consumed. Respondents from the Tulalip Tribes purchased a mean of approximately two-thirds of fish from grocery stores or restaurants, while among the Squaxin Island Tribe, the source of fish was about 50% self-caught and 50% purchased from grocery stores or restaurants. For bottom fish, members of both tribes caught about half of the fish they consumed. Anadromous fish were much more likely to be consumed with the skin attached. Most other fish were consumed minus the skin. Approximately 10% of the respondents consumed parts of the fish other than muscle; i.e., head, bones, eggs.

Data on fish consumption were obtained for 263 members from the Tulalip and Squaxin Island tribes. The mean consumption rate for women of both tribes was between 10-and-12-times higher than the default rate of 6.5 grams/day used by some parts of the U.S. government to estimate fish intake. Among male members of both tribes, the consumption rate was approximately 14-times higher than the default rate. The 50th percentile consumption rate for finfish for both tribes combined was 32 grams/kg body weight/day. Male members of the Tulalip and Squaxin Island tribes had average body weights of 189 pounds and 204 pounds, respectively. Female members of the Tulalip and Squaxin Island tribes weighed on average 166 pounds and 150 pounds, respectively. If an average body weight is assumed to be 70 kg, the daily fish consumption rate for both tribes for adults was 73 grams per day with a 90th percentile value of 156 grams per day for total fish. Fish consumption data for selected categories of fish are shown in Table 4-33.

Table 4-33
Fish Consumption (gms/kg bw/day) by the Tulalip and Squaxin Island Tribes
(Toy et al., 1995)

Type of Fish	5th Percentile	50th Percentile	90th Percentile	95th Percentile	Mean	SE	95th Percent CI
Anadromous	.0087	.2281	1.2026	1.9127	.4600	.0345	.3925, 0.5275
Pelagic	.0000	.0068	.1026	.2248	.0390	.0046	.0300, 0.0480
Bottom	.0000	.0152	.1095	.2408	.0482	.0060	.0364, 0.4375
Shell Fish	.0000	.1795	1.0743	1.4475	.3701	.0343	.3027, 0.4375
Other Fish	.0000	.0000	.0489	.1488	.0210	.0029	.0152, 0.0268
Total Finfish	.0200	.3200	.1350	2.1800	.5745	.0458	.4847, 0.6643
Total All Fish	.0495	.6081	2.2267	3.2292	1.0151	.0865	.8456, 1.1846

During the survey period, 21 of the 263 tribal members surveyed reported fish consumption rates greater than three standard deviations from the mean consumption rate. For example, six subjects reported consumptions of 5.85, 6.26, 9.85, 11.0, 22.6 and 11.2 grams of finfish and shell fish/kg body weight/day. If a 70-kg body weight is assumed these consumption rates correspond to 410, 438, 690, 770 and 1582 grams per day.

Mohawk Tribe

A study of fish consumption among 97 nursing Mohawk women in rural New York State was conducted from 1986 to 1992 (Fitzgerald et al., 1995). Fish consumption advisories had been issued in the area due to polychlorinated biphenyl (PCB) contamination of the local water body. Using food frequency history and a long-term dietary history, the women were asked about their consumption of locally caught fish during three specific periods of time: during pregnancy, the year prior to pregnancy, and more than a year before pregnancy. For comparison, the study also surveyed fish consumption rates among 154 nursing (primarily caucasian) women from neighboring counties. The socioeconomic status of the women of the control group were similar to that of the Mohawk women. The fish in these counties had background PCB concentrations.

The results (Table 4-34) showed that the Mohawk women had a higher prevalence of consuming locally caught fish than the comparison group in the two intervals assessed prior to the pregnancy; the prevalence of local fish consumption during pregnancy for the two groups was comparable. A decrease in local fish consumption rates was also noted over time; these may be related to the issuance of advisories.

Table 4-34
Local Fish Meals Consumed By Time Period for the Mohawk and Comparison Nursing Mothers (Fitzgerald et al., 1995)

Fish Meals/ Year	During Pregnancy		1 Year Before Pregnancy		>1 Year Before Pregnancy	
	Mohawk	Control	Mohawk	Control	Mohawk	Control
0	64.9%	70.8%	43.3%	64.3%	20.6%	60.4%
1-9	24.7%	15.6%	41.2%	20.1%	43.3%	22.7%
10-19	5.2%	4.5%	4.1%	3.9%	6.2%	5.2%
>19	5.1%	9.1%	11.3%	11.7%	29.9%	11.7%

Native Americans near Clear Lake, California

Harnly et al. (1997) found that Native Americans living near Clear Lake, California consumed an average of 84 grams of fish/day (60 g/day sport fish plus 24 g/day of commercial fish). Ten percent of adults reported mercury intakes over 30 μg/day. The most popular species of sportfish were: catfish, perch, hitch, bass, and carp. Commercial species most commonly eaten were: snapper, tuna, salmon, crab, and shrimp.

Great Lakes Tribes

Members of the Ojibwa live in the Great Lakes region of the United States and Canada. Gerstenberger et al. (1997) reported that approximately 35% of the respondents (89 members of the Ojibwa Tribes) consumed Lake Superior fish at least once a week with 7% of this group consuming Lake Superior fish at least twice a week. The most commonly consumed Lake Superior-origin fish were lake trout, walleye, and whitefish. In addition, fish were consumed from inland lakes with 12% of reponsdnets eating inland lake fish once a week and 6% consuming these fish twice a week. Walleye was the most common species of fish consumed from these inland lake sources.

4.1.4 Summary of Hawaiian Island Fish Consumption Data

The CSFII 1989-1991 did not include the Hawaiian Islands. To the knowledge of the authors of the Mercury Study Report to Congress, data describing fish consumption by the general Hawaiian population that estimate Island-wide levels of consumption have not been reported. However, reports on commercial utilization of seafood (Higuchi and Pooley, 1985; Hudgins, 1980) and analysis of epidemiology data (Wilkens and Hankin, personal communication, 1996) provide a basis to describe general patterns of consumption. Overall, seafood consumption in Hawaii is much higher than in the contiguous United States. On a per capita basis, the United States as a whole consumed 5.45 kg and 5.91 kg (12 and 13 pounds) of seafood in 1973 and 1977, respectively (Hudgins, 1980). By contrast Hawaiian per capita consumption for all fish products was 11.14 kg (24.5 pounds) in 1972 and 8.77 kg (19.3 pounds) in 1974.

The most popular species of fish and shellfish consumed were moderately comparable between Hawaii and the contiguous 48 states. The methods of food preparation differed, however, with raw fish being far more commonly consumed in Hawaii. Sampled at the retail trade level the most commonly purchased fish were: tuna, mahimahi, and shellfish [see Table 4-35 which is based on data in Higuchi and Pooley (1985)]. A survey of seafood consumption by families was identified. In 1987, the Department of Business and Economic Development (State of Hawaii, 1987) conducted a survey of 400 residents selected on a random digit dialing basis of a population representing 80% of total state seafood consumption. All data were collected in July and August, 1987 and would not reflect any seasonal differences in fish/shellfish consumption. The respondents were asked to describe seafood consumption by their families. Shrimp was the most popular seafood with mahimahi or dolphin fish as the second most popular (Hawaii Seafood, 1988). Reports on fish consumption in Hawaii separate various species of tuna: ahi (Hawaiian yellowfin tuna, bigeye tuna & albacore tuna), aku (Hawaiian skipjack tuna), and tuna. In 1987, nearly 66% of the 400 families surveyed had seafood at least once a week and 30% twice a week. Only 4% did not report consuming seafood during the previous week based on a telephone survey.

Wilkens and Hankin (personal communication, 28 February 1996) analyzed fish intake from 1856 control subjects from Oahu who participated in research studies conducted by the Epidemiology Program of the Cancer Research Center of Hawaii, University of Hawaii at Manoa. These subjects were asked about consumption over a one-year period prior to the interview. Within this group the most commonly consumed fish was tuna [canned with tuna species undesignated (70.8 % of subjects reporting consumption)]; shrimp (47.7% of subjects); tuna (yellowfin fresh designated aku, ahi with 42.2% of subjects reporting consumption); mahimahi [(or dolphin) with 32.5% of respondents reporting consumption]; and canned sardines (with 29.1% of subjects reporting consumption).

Table 4-35
Species Composition of Hawaii's Retail Seafood Trade — 1981 Purchases
Higuchi and Pooley (1985)

Fish/Shellfish	Pounds Purchased	Percent of Total Purchases
Tuna Ahi (Hawaiian yellow-fin, bigeye & albacore)	11,600,000 (5,400,000)	20.9
Billfish (including swordfish) and shark	5,900,000	11.3
Mahimahi and ono (wahoo)	9,900,000	17.7
Akule (Hawaiian bigeye scad) and opelu	4,00,000	6.9
Bottom fish	2,600,000	7.0
Reef fish	3,500,000	5.3
Shellfish Shrimp Lobster	8,200,000 (4,200,000) (900,000)	15.5
Other species Salmon/trout Snapper Frozen filets Frozen sticks/blocks	8,300,000 (1,500,000) (1,800,000) (2,300,000) (1,400,000)	15.4
Total	**54,000,000**	**100.0**

4.1.5 Summary of Alaskan Fish Consumption Data

The CSFII analyses of food intake by the USDA include the 48 contiguous states but do not include Alaska or Hawaii. A number of investigators have published data on fish consumption in Alaska by members of native populations (e.g., Inuits, Eskimos) and persons living in isolated surroundings. These reports focus on nutritional/health benefits of high levels of fish consumption, food habits of native populations, and/or effects of bioaccumulation of chemicals in the aquatic food web.

4.1.5.1 General Population

After contacting professionals from the Alaskan health departments and representatives of the U.S. Centers for Disease Control in Anchorage, the authors of this report have not identified general population data on fish consumption among Alaskan residents who are not part of native population groups, subsistence fishers/hunters, or persons living in remote sites. Patterns of fish consumption among urban residents (e.g., Juneau, Nome, Anchorage) appear not to be documented in the published literature.

4.1.5.2 Non-urban Alaskan Populations

Native people living in the Arctic rely on traditional or "country" foods for cultural and economic reasons. The purpose of the current discussion is not to assess the comparative risks and benefits of these foods. The risks and benefits of these food consumption habits have been compared by many investigators and health professionals (among others see Wormworth, 1995; Kinloch et al., 1992; Bjerregaard, 1995).

Despite a degree of acculturation in the area of foods, native foods were still eaten frequently by Alaskan Native peoples based on results of the 1987-1988 survey. Diets that include major quantities of fish (especially salmon) and sea mammals retain a major place in the lives of Alaskan Native peoples. The consumption of traditional preparations of salmon and other fish continues; this includes fermented foods such as salmon heads and eggs, other fish and their eggs, seal, beaver, caribou and whale.

Diets of Native Alaskans differ from the general population and rely more extensively on fish and marine mammals. These are population groups that are characterized by patterns of food consumption that reflect availability of locally available foods and include food preparation techniques that differ from those usually identified in nutrient data bases. For example, Nobmann et al. (1992) surveyed a population of Alaska Natives that included Eskimos (53%), Indians (34%), and Aleuts (13%). The distribution of study participants was proportional to the distribution of Alaska Natives reported in the 1980 Census. The 1990 Census identified an overall population of 85,698 persons as Alaska Natives.

Nobmann et al. (1992) indicated that Alaska Natives have traditionally subsisted on fish; marine mammals; game; a few plants such as seaweed, willow leaves, and sourdock; and berries such as blueberries and salmonberries rather than on a plant-based diet. In preparing a nutrient analysis of the food consumed in eleven communities that represented different ethnic and socioeconomic regions of Alaska, these investigators added nutrient values for 210 foods consumed by Alaska Natives in addition to the 2400 foods present in the Veteran's Administration's nutrient data base. Nobmann et al. (1992) found fish were an important part of the diet. The mean daily intake of fish and shellfish of Alaska Natives was 109 grams/day. Fish consumption was more frequent in the summer and fall and game meat was eaten more often in the winter.

Quantitative information on dietary intakes of Native Alaskan populations are few. Estimates can be derived from harvest survey data, but these have limitations because not all harvested animals are consumed nor are all edible portions consumed. Other edible portions may be fed to domestic animals (e.g., sled dogs). Substantial variability in intake of foods including ringed seal, bearded seal, muktuk (beluga skin with an underlying thin layer of fat) and walrus has been reported (Ayotte et al., 1995).

Dietary analyses on seasonal food intakes of 351 Alaska Native adults from eleven communities were performed during 1987-1988 (Nobmann et al., 1992). Alaska Natives include Eskimos, Indians and Aleuts. There is no main agricultural crop in Alaska which when combined with a short growing season, results in limited availability of edible plants. Alaska Natives have traditionally relied on a diet of fish, sea mammals, game and a few native plants (seaweed, willow leaves, and sourdock) and berries (such as, blueberries and salmon berries). Although consumption of significant amounts of commercially produced foods occurs, use of subsistence foods continues.

The survey sample of 351 adults, aged 21-60 years, was drawn from eleven communities. Information was obtained using 24-hour dietary recalls during five seasons over an 18-month period. Fish were consumed much more frequently by Alaska Natives than by the general U.S. population. Fish ranked as the fourth most frequently consumed food by Alaska Natives compared with the 39th most frequently consumed food by participants in the nationally representative Second National Health and Nutrition Assessment Survey (NHANES II). The mean daily intake of fish and shellfish for Alaska Natives was 109 grams/day contrasted with an intake of 17 grams per day for the general U.S. population described in NHANES II. Among Alaska Natives fish was consumed more frequently in the summer and fall months.

Several extensive data sets on mercury concentrations in marine mammals consumed by indigenous populations living in the circumpolar regions have been published (Wagemann et al., 1996; Caurant et al., 1996; Dietz et al., 1996). Analyses that determined chemically speciated mercury have shown that mercury present in muscle tissue is largely (>75%) organic mercury (i.e., methylmercury (Caurant et al., 1996)). By contrast, mercury present in organs such as liver and kidney is predominantly in an inorganic form (Caurant et al., 1996).

4.1.5.3 Alaskans from Subsistence Economies

Wolfe and Walker (1987) described the productivity and geographic distribution of subsistence economies in Alaska during the 1980s. Based on a sample of 98 communities, the economic contributions of harvests of fish, land mammals, marine mammals and other wild resources were analyzed. Noncommercial fishing and hunting play a major role in the economic and social lives of persons living in these communities. Harvest sizes in these communities were established by detailed retrospective interviews with harvesters from a sample of households within each community. Harvests were estimated for a 12-month period. Data were collected in pounds of dressed weight per capita per year. Although it varies by community and wildlife species, generally "dressed weight" is approximately 70 to 75% of the round weight for fish and 20 to 60% of round weight for marine animals. Dressed weight is the portion of the kill brought into the kitchen for use, including bones for particular species. The category "fish" contains species including salmon, whitefish, herring, char, halibut, and pike. "Land mammals" included species such as moose, caribou, deer, black bear, snowshoe and tundra hare, beaver and porcupines. "Marine mammals" consisted of seal, walrus and whale. "Other" contained birds, marine invertebrates, and certain plant products such as berries.

Substantial community-to-community variability in the harvesting of fish, land mammals, marine mammals and other wild resources were noted (Wolfe and Walker, 1985). Units are pounds "dressed weight" per capita per year. The median harvest was 252 pounds with the highest value approximately 1500 pounds. Wild harvests (quantities of fish, land mammals and marine mammals) in 46% of the sampled Alaskan communities exceeded the western U.S. consumption of meat, fish, and poultry. These communities have been grouped by general ecological zones which correspond to historic/cultural areas: Arctic-Subarctic Coast, Aleutian-Pacific Coast, Subarctic Interior, Northwest Coast and contemporary urban population centers. The Arctic-Subarctic Coast displayed the greatest subsistence harvests of the five ecological zones (610 pounds per capita), due primarily to the relatively greater harvests of fish and marine animals. For all regions the fishing output is greater than the hunting; fishing comprises 57 - 68% of total subsistence output. Above 60° north latitude fishing predominates other wildlife harvests, except for the extreme Arctic coastal sea mammal-caribou hunting communities. Resource harvests of fish ("dressed weight" on a per capita basis) by ecological zone (and cultural area) were these: Arctic-Subarctic Coast (Inupiaq-Yup'ik), 363 pounds/year or 452 grams/day; Aleutian-Pacific Coast (Aleut-Sugpiaq), 251 pounds/year or 312 grams/day; Subarctic Interior (Athapaskan), 256 pounds/year or 318 grams/day; Northwest Coast (Tingit-Haida), 122 pounds/year or 152 grams/day; and Other (Anchorage, Fairbanks, Juneau, Matanuska-Susitna Borough, and Southern Cook Inlet), 28 pounds/year or 35 grams/day.

Consumption of marine mammals was reported among Yupik Eskimos living in either a coastal or river village of southwest Alaska (Parkinson et al., 1994). Concentrations of plasma omega-3 fatty acids were elevated (between 6.8 and 13 times) among the Yupic-speaking Eskimos living in two separate villages compared with non-Native control subjects (Parkinson et al., 1994). Concentrations of omega-3 fatty acids in plasma phospholipid has been shown to be a valid surrogate of fish consumption (Silverman et al., 1990). Among coastal-village participants the concentrations of eicosapentaonoic and docosahexaenoic acids reflected higher consumption of marine fish and marine mammals and the use of seal oil in food preparation. Among river village natives, the increase reflected higher consumption of salmon.

The Division of Subsistence of the Alaska Department of Fish and Game (Robert J. Wolfe, personal communications, 1997) has provided estimates of the mean per capita harvests of subsistence fish, shellfish, and marine mammals in rural Alaska areas (Table 4-36). Combined harvests of fish/shellfish/marine mammals averaged approximately 350 grams/day for all rural areas combined. The highest intakes were found in the Western, Interior and Arctic regions with harvests of 693, 577, and 482 grams/day, respectively. Marine mammal consumption was particularly high in the Arctic region with an average of approximately 270 grams/day consumed. Comparable estimates of marine mammal consumption were reported by Chan (1997) for an Inuit community based on dietary information gathered by the Centre for Indigenous Peoples' Nutrition and the Environment (Table 4-37). Using the Centre's database for contaminants, Chan estimated that mercury intakes were 185 μg mercury/day with 170 μg of mercury coming from marine mammal meat.

Consumption of marine mammals results in very high exposures to methylmercury. Wolfe (1997) provided data on mean per capita harvest of marine mammals in the Arctic region of rural Alaska of about 290 grams/day. Greater details of types of marine mammals consumed, mercury concentrations found in these mammals, and estimates of quantities of mammals consumed have been published by Canadian investigators (Jensen et al. 1997; Chan, 1997) and by the investigators in Greenland and Denmark (Dietz et al., 1996).

Table 4-36
Mean Per Capita Harvest of Fish and Marine Mammals (g/day)
(Wolfe, personal communication, 1997)

Alaska Rural Area	Fish	Shellfish	Marine Mammals	Fish/Shellfish	Fish/Shellfish/ Marine Mammals
Southcentral-Prince William Sound	114	7	4	122	126
Kodiak Island	132	17	2	149	152
Southeast	119	32	7	152	159
Southwest-Aleutian	299	7	12	307	319
Interior	577	0	0	577	577
Arctic	194	1	267	195	482
Western	605	0	88	605	693
All Rural Areas Combined	276	11	65	267	352

Table 4-37
Estimated Daily Intake of Food and Mercury for Arctic Inuit
(Adapted from Chan, 1997)

Food group	**Food (g/day)**	**Mercury (µg/day)**
Marine mammal meat	199	170
Marine mammal blubber	30	2.4
Terrestrial mammal meat	147	4.0
Terrestial mammal organs	1	0.9
Fish	42	6.6
Birds	2	0.8
Plants	2	0.0
Total	423	185

Marine mammals are primarily exposed to methylmercury (Caurant et al., 1996). Mercury present in flesh of marine mammals is largely methylmercury. For example, Caurant et al. (1996) identified an average of 78% organic mercury in muscle of pilot whales (*Globicepala melas*) and 23% organic mercury in pilot whale liver. Mercury in organs such as liver and kidney appears to be demethylated and stored in a form combined with selenium, which has been regarded as a detoxification mechanism for the marine mammals (Caurant et al., 1996). Detailed date on mercury concentration in the northern marine ecosystem were reported by Dietz et al. (1996) including information on mercury concentration in molluscs, crustaceans, fish, seabirds, seals, whales, and polar bears.

Among the Inuit in coastal communities of the Canadian Arctic and Greenland, marine mammals are an important source of food. Food items include the flesh and some organs of ringed seals (*Phoca hispida*) and the flesh, but preferentially skin meat and liver of ringed seals and muktuk and blubber of whales are eaten raw or cooked. Muktuk and the flesh, liver, intestines, and blubber of walrus are also eaten after fermentation (Wagemann et al., 1996).

Throughout the Arctic, the mean mercury concentration in muscle of beluga whale averaged between 0.7 and 1.34 µg mercury/gram wet weight of tissue (Wagemann et al., 1996). Muktuk (skin as a whole) of beluga averaged between approximately 0.6 and 0.8 µg mercury/g wet weight. The skin of cetaceans (whales, dolphins, porpoises) consists of four layers with the mercury concentration increasing toward the outermost layers of skin. In this outermost layer of skin, mercury concentration were about 1.5 µg/gram. During molting, about 20% of the total mercury in skin is lost annually. Muscle tissue of narwhal averaged between 0.8 and 1.0 µg/g, while muktuk averaged around 0.6 µg/g wet weight (Wagemann et al., 1996). Muscle flesh of ringed seals had average mercury concentrations in the range of 0.4 and 0.7 µg/g with most of the mercury present as methylmercury. Liver mercury concentrations averaged in the range of 20 to 30 µg/g, but this was primarily present as inorganic mercury. Kidney contained between 1 and 3 ppm mercury (Wagemann et al., 1996).

Overall, groups consuming muscle and muktuk from marine mammals have much higher exposures to methylmercury that do groups who consume primarily fish and/or terrestrial mammals. Chan (in press) estimated exposures over 180 µg mercury/day for Arctic Inuits. To whatever extent organs (specifically liver and kidney) are consumed, these typically contain higher concentrations of mercury but with a lower fraction of methylmercury than found in muscle tissue.

4.1.6 Summary of Canadian Data on Mercury Intake from Fish and Marine Mammals

The Northern Contaminants Program on the Department of Indian Affairs and Northern Development of the Canadian Government published a compilation of contaminant data including mercury concentrations in fish and marine mammals (Jensen et al., 1997). Most of the traditionally harvested fish and land and marine animals consumed are long-lived and are from the higher trophic levels of the food chain which contain greater concentrations of methylmercury than are found in nonpredatory fish.

Several extensive data sets on mercury concentrations in marine mammals consumed by indigenous populations living in the circumpolar regions have been published (Wagemann et al., 1996; Caurant et al., 1996; Dietz et al., 1996). Analyses that determined chemically speciated mercury have shown that mercury present in muscle tissue is largely (>75%) organic mercury (i.e., methylmercury) (Caurant et al., 1996). By contrast, mercury present in organs such as liver and kidney is predominantly in an inorganic form (Caurant et al., 1996).

Wagemann et al. (1997) have provided an overview of mercury concentrations in Arctic whales and ringed seals. The Inuit in coastal communities of the Canadian Arctic and Greenland hunt and consume marine mammals for food. The flesh and some organs of ringed seals (*Phoca hispida*) and flesh but preferentially skin (muktuk) of belugas (*Delphinapterus leucas*) and narwal (*Monodon monoceros*) contribute significantly to the Inuit diet. Throughout the Arctic, the mean concentrations in Beluga muscle averaged 0.70 to 1.34 µg mercury/gram wet weight (Wagemann et al., 1996). Mean mercury concentrations in the muktuk (skin as a whole) of belugas sampled in the western (1993-1994) and the eastern Arctic (1993-1994) were 0.78 and 0.59 µg mercury/gram wet weight (Wagemann et al., 1996). Mean mercury concentrations for narwhal samples collected in the period 1992-1994 were 0.59, 1.03, 10.8, and 1.93 µg mercury/gram wet weight in muktuk, muscle, liver, and kidney, respectively (Wagemann et al., 1996). Muscle tissue of ringed seals contained mercury in concentrations averaging between 0.4 and approximately 0.7 µg mercury/gram wet weight. Liver tissue averaged between approximately 8 and 30 µg mercury/gram wet weight. Kidney tissues averaged between 1.5 and 3.2 µg mercury/gram wet weight.

Extensive data on mercury concentrations in multiple tissues from a wide variety of molluscs, crustacea, fish, seabirds, and marine mammals (seals, whales, and porpoises), and polar bears collected in Greenland were published by Dietz et al. (1996). Chemically speciated mercury concentrations in tissues of pilot whales have been determined by Caurant et al. (1996). The percent organic mercury (i.e., methylmercury) in muscle tissue averaged over 75%. Liver contained a smaller fraction organic mercury, averaging approximately 23% organic mercury. Marine mammals are principally exposed to methylmercury, which is the main physico-chemical form of storage in fish (Caurant et al., 1996). Although demethylation by liver may serve as a means of protecting the marine mammal against adverse effects of methylmercury, the presence of organic mercury in the marine mammal's muscle means that consumption of flesh from these mammals will result in exposure to organic mercury.

Jensen et al. (1997) in the *Canadian Arctic Contaminants Assessment Report* identified wide variability in the consumption of fish and marine mammals by various aboriginal groups. Chan (1997) summarized results from an extensive number of dietary surveys of Northern peoples from the Dene (registered Indian) communities and the Inuit communities (Tables 4-38 and 4-39). The Dene were estimated to have a mean consumption of 80 grams/day of fish. The Inuit communities were estimated to have a fish consumption of 42 grams/day, a marine mammal consumption of approximately 230 grams/day

Table 4-38
Mercury Concentrations (µg Hg/g wet weight) in Traditional Foods Consumed by Canadian Aboriginal Peoples
(Modified from Chan, 1997)

Food Group	Number of Sites	Number of Samples	Arithmetic Mean	Standard Deviation	Maximum
Marine Mammal Meat	32	764	0.85	1.05	33.4
Marine Mammal Blubber	6	71	0.08	0.05	0.13
Terrestrial Mammal Meat	6	19	0.03	0.02	0.17
Terrestrial Mammal Organs	14	254	0.86	0.90	3.06
Fish	799	31,441	0.46	0.52	12.3
Birds	24	216	0.38	0.59	4.4
Plants	8	14	0.02	0.02	0.05

Table 4-39
Estimated Daily Intake of Mercury Using Contaminant Data Base and Dietary Information from Dene and Inuit Communities in Canada
(Adapted from Chan, 1997)

Food Group	Dene Community		Inuit Community	
	Food (g/day)	Mercury (µg/day)	Food (g/day)	Mercury (µg/day)
Marine Mammal Meat	0	0	199	170
Marine Mammal Blubber	0	0	30	2
Terrestrial Mammal Meat	205	6	147	4
Terrestrial Mammal Organs	23	20	1	1
Fish	80	13	42	7
Birds	8	1	2	1
Plants	2	0	2	0.0
Total	318	40	423	185

(199 grams of meat and 30 grams of blubber). These mean consumptions were associated with a mercury intake of 39 µg mercury/day for the Dene community and 185 µg mercury/day for an Inuit community. For the Inuit community, 170 µg mercury/day came from marine mammal meat.

4.2 Trends in Fish and Shellfish Consumption in the United States

Description of long-term trends in fish and shellfish consumption are based on data provided by the National Marine Fisheries Service of the U.S. Department of Commerce. Detailed information on trends in the 1990s, and forecasts for future production and consumption of fish and shellfish, are based on projections described in the *Annual Report on the United States Seafood Industry* published by H.M. Johnson & Associates (1997).

4.2.1 Fish and Shellfish Consumption: United States, 1975 to 1995

Data for the U.S. consumption and utilization of fish and shellfish have been obtained from the World Wide Web (http://remora.ssp.mnfs.gov/commercial/landings/index.html). Landings are reported in pounds of round (i.e., live) weight for all species or groups except univalve and bivalve molluscs, such as clams, oysters, and scallops. For the univalves and bivalve molluscs, landings are reported as pounds of meat which excludes shell weight. Landings to not include aquaculture products except for clams and oysters. Aquaculture products are an increasing source of fish and shellfish for some species of seafood (Johnson 1997).

U.S. per capita consumption of commercial fish and shellfish has increased from the early part of this century until present. The major increases occurred post-1970. In 1910, for example, U.S. citizens consumed an average of 11.0 pounds (edible meats) of commercial fish and shellfish. The consumption in 1970 was 11.8 pounds per capita, but by 1990 had increased to 15.0 pounds per capita.

Two major differences are associated with this trend. First, there was a major increase in population from 92.2 million persons in 1910, to 201.9 individuals in 1970s, and 247.8 million citizens in 1990. In 1995 (the latest year this source provide statistics), the civilian resident population was estimated at 261.4 million persons. Combined with increased consumption on a per capita basis, the seafood market has dramatically increased throughout this century.

The second major change was in availability of transportation and in food processing. Changes between 1910 and 1995 are shown in Table 4-40. Consumption of cured fish dramatically decreased from about 36% of per capita intake in 1910, to 2.0% in 1990. Fresh or frozen fish were about 40% of per capita intake in 1910 and increased to about 67% (two-thirds) of fish and shellfish intake by 1990 and 1995. The consumption of canned fish and shellfish changed the least representing about one-fourth of all fish/shellfish intake in 1910 and about one-third of intake in 1990 and 1995.

Table 4-40
Percent of Fish/Shellfish by Processing Type between 1910 and 1995
(Source: National Marine Fisheries Service, 1997)

Year	Fresh/Frozen	Canned	Cured
1910	39.1	24.5	36.4
1970	58.5	38.1	4.0

1990	64.7	33.3	2.0
1995	66.7	31.3	2.0

4.2.1.1 United States: Major Imports and Exports of Fish and Shellfish

During the period 1990 through 1994 the United States was the second largest importer of seven fishery commodity groups, as well as the second largest exporter of these groups. The largest importer was Japan and the third largest importer (after the United States) was France followed by Spain, Germany, and Italy. On a value basis, Canada in the second largest trading partner for the United States after Japan (Johnson, 1997).

The top five exporters of seafood were Thailand, United States, Norway, Denmark, and China. Thailand is the leading supplier of seafood to the United States on a value basis, shipping primarily shrimp (Johnson, 1997). Canada was the leading seafood supplier on a volume basis (Johnson, 1997). The seven fishery commodity groups are:

1. Fish, fresh, chilled or frozen;
2. Fish, dried, salted, or smoked;
3. Crustaceans and mollusks, fresh, dried, salted, etc.;
4. Fish products and preparations, whether or not in airtight containers;
5. Crustacean and mollusk products and preparations, whether or not in airtight containers;
6. Oils and fats, crude or refined, or aquatic animal origin; and
7. Meals, soluble and similar animal food stuffs of aquatic animal origin.

4.2.1.2 U.S. Supply of Edible Commercial Fishery Products: 1990 and 1995

The supply of the products shown in Table 4-41 is expressed as round or live weight. Any comparison of these values with food consumption data must consider that the edible portion is smaller than the live weight. Factors for edible portion compared with live/round weight were published in the National Research Council's report on *Seafood Safety* (NRC/NAS, 1990). Total U.S. consumption of fish and shellfish must also include self-caught and recreationally caught fish, as well as other sources that are not tabulated through commercial channels.

Table 4-41
U.S. Supply of Edible Commercial Fishery Products: 1990 and 1995
(Round or Live Weight in Million Pounds)
Source: National Marine Fisheries Service

Year	Domestic Commercial Landings		Imports		Total
	Million Pounds	Percent	Million Pounds	Percent	Million Pounds
1990	7,041	55.6	5,621	44.4	12,662
1995	7,783	56.8	5,917	43.2	13,700

4.2.1.3 U.S. Annual Per Capita Consumption of Canned Fishery Products: 1990 and 1995

Canned tuna is the predominant type of canned fish consumed in the United States averaging 72.4% of all canned fish consumed per capita. Table 4-42 shows U.S. annual per capita consumption of canned fishery products in 1990 and 1995.

Table 4-42
U.S. Annual Per Capita Consumption of Canned Fishery Products: 1990 and 1995
(Pounds Per Capita)

Year	Salmon	Sardines	Tuna	Shellfish	Other	Total
1990	0.4	0.3	3.7	0.3	0.4	5.1
1995	0.5	0.2	3.4	0.3	0.3	4.7

4.2.1.4 U.S. Annual Per Capita Consumption of Fish Items: 1990 and 1995

In fresh and frozen fish products and shrimp, per capita consumption in these categories is shown in Table 4-43 based on data from the National Marine Fisheries Service.

Table 4-43
U.S. Annual Per Capita Consumption (in pounds*) of Certain Fishery Items: 1990 and 1995

Year	Fillet and Steaks **	Sticks and Portions	Shrimp (All Preparations)
1990	3.1	1.5	2.2
1995	2.9	1.2	2.5

** Product weight of fillets and steaks and sticks and portions, edible (meat) weight of shrimp.*
*** Data include ground fish and other species. Data do not include blocks, but fillets could be made into blocks from which sticks and portions could be produced.*

4.2.1.5 Major Imported Fish and Shellfish Products

The two major fish/shellfish products imported into the United States in 1994 and 1995 (expressed by weight) were shrimp (621,618,000 pounds in 1994 and 590,634,000 pounds in 1995), and tuna (including albacore, canned tuna, and other tuna: 707,426,000 pounds in 1994 and 711,241,000 pounds in 1995). Approximately 28% of imported tuna was imported as albacore tuna and about 33% was imported as canned tuna. Shrimp imports were not differentiated by species of shrimp or country of origin in the national Marine Fisheries Service statistics.

4.2.2 Current Market Trends, 1996

The following data on current market trends in the seafood industry are abstracted from the *1997 Annual Report on the United States Seafood Industry* describing 1996 data on seafood by H.M. Johnson & Associates (Johnson, 1997).

The world commercial fish and shellfish supplies increased from 109.6 thousand metric tons in 1994 to 112.0 thousand metric tons in 1995. Aquaculture provided the largest boost to world supply in 1995 increasing 13.6% over the previous year. During this period (1995 to 1996) capture fisheries declined by 0.1 metric tons. Aquaculture represents 26% of all world food fish (total supply less reduction fish) products.

The Food and Agriculture Organization examined long-term trends in 77 major fish resources (representing 77% of the world marine fish landings) are concluded that 35% of the resources were "overfished," 25% were "fully fished," and 40% had remaining capacity for expansion (FAO, 1996; as cited by Johnson, 1997).

Aquaculture

World aquaculture continued to increase with 1995 production increased by 14% to 20.9 million metric tons (Johnson, 1997). Five Asian countries (China, India, Japan, Republic of Korea, and the Philippines) supplied 80% of aquaculture-raised fish/shellfish. World-wise aquaculture is predicted by the Food and Agriculture Organization to continued to increase fish and shellfish production beyond the years 2000.

Within the United States, domestic finfish aquaculture increased in 1996. The major increases were in catfish production. Catfish production very much dominates the U.S. finfish aquaculture production yielding approximately 475 million pounds round weight/year. Tilapia harvests were higher in 1996, however, trout and salmon production declined. Salmon, trout, and tilapia production are substantially smaller than catfish production. Yields from U.S. aquaculture for salmon, trout, and tilapia were under 50 million pounds for each of these species.

4.2.3 Patterns in Fish and Shellfish Consumption: United States, 1996

4.2.3.1 Overall Patterns

Between 1995 and 1996 there was a 0.2 pound decrease in per capita consumption of seafood in the United States. The principal decline was in canned tuna. The top ten seafoods consumed (expressed as pounds consumed per capita) were: canned tuna (3.2), shrimp (2.5), Alaska Pollock (1.6); salmon (1.4); cod (just under 1 pound); catfish (approximately 0.9 pounds); clams (approximately 0.5 pounds), flatfish (0.4 pounds), crab (approximately 0.3), and scallops (0.3). The source of these data are the National Marine Fisheries Service and the *1997 Annual Report on the United States Seafood Industry* (Johnson, 1997).

4.2.3.2 Fish Intake among Adults

Analysis of the frequency of reporting of fish/shellfish and menu items containing fish and shellfish was carried out using data from CSFII 1994 and CSFII 1995. Seasons were grouped into six two-month intervals; i.e., Jan/Feb, Mar/Apr, etc. Data for the 10 most commonly consumed menu items are shown in Table 4-44. The most frequently reported menu items are "seafood salads and seafood and vegetable dishes." Although other fishery products are possible, this menu category typically describes dishes made with tuna, surimi (i.e., Alaska pollock), crab, salmon or other canned fish or shellfish. Overall, these dishes represent about 20% of overall seafood consumption. This major group is followed by shrimp, canned tuna, the group “Seafood cakes, fritters, and casseroles without vegetables”. Identified finfish commonly consumed include salmon, cod, catfish, flounder, trout, seabass, ocean perch, haddock, and porgy. Although specific finfish are identified as among the top ten consumed over six seasons, they follow consumption of processed fishery products; e.g., salads, fritters, “fast food” fillets, and shrimp.

Table 4-44
Ten Most Commonly Reported Fish/Shellfish/Mixed Dishes by Season
CSFII 1994 and CSFII 1995 — Day 1 Data

Ranking	***Season***					
	Jan/Feb	**Mar/Apr**	**May/Jun**	**Jul/Aug**	**Sep/Oct**	**Nov/Dec**
1st	Seafood salads, & seafood & vegetable dishes, 17.6%	Seafood salads, & seafood & vegetable dishes, 16.9%	Seafood salads, & seafood & vegetable dishes, 24.5%	Seafood salads, & seafood & vegetable dishes, 23.2%	Seafood salads, & seafood & vegetable dishes, 15.4%	Seafood salads, & seafood & vegetable dishes, 20.0%
2nd	Shrimp, 11.2%	Shrimp, 10.5%	Shrimp, 9.5%	Seafood cakes, fritters, & casseroles w/o vegetables, 7.9%	Tuna, canned 12.0%	Shrimp, 11.1%
3rd	Seafood cakes, fritters & casseroles w/o vegetables, 8.8%	Tuna, canned, 10.1%	Tuna, canned, 6.8%	Tuna, canned 7.5%	Shrimp, 11.5%	Seafood cakes, fritters & casseroles w/o vegetables, 10.0%
4th	Catfish, 8.3%	Seafood cakes, fritters, & casseroles w/o vegetables, 8.1%	Seafood cakes, fritters, & casseroles w/o vegetables, 6.4%	Salmon, 6.8%	Seafood cakes, fritters, & casseroles w/o vegetables, 8.7%	Fish stick/fillet, 9.4%
5th	Fish stick/fillet 7.8%	Cod, 5.6%	Fish stick,fillet 5.5%	Shrimp, 6.4%	Fish stick/fillet, 6.7%	Fish stick/fillet, 9.4%

Table 4-44 (continued)
Ten Most Commonly Reported Fish/Shellfish/Mixed Dishes by Season
CSFII 1994 and CSFII 1995 — Day 1 Data

Ranking	***Season***					
	Jan/Feb	**Mar/Apr**	**May/Jun**	**Jul/Aug**	**Sep/Oct**	**Nov/Dec**
6th	Tuna, canned, 6.3%	Salmon, 5.2%,	Salmon, 4.5%	Fish stick/fillet, 5.4%	Cod, 6.3%	Tuna, canned 7.8%
7th	Salmon, 3	Fish, unspecified, 4.8%	Seafood sandwiches, 4.1%	Catfish, 4.6%	Fish, unspecified 4.8%	Salmon, 4.4%
8th	Trout, 2.4%	Seafood sandwiches, 4.0%	Fish, unspecified 3.6%	Cod, 4.6%	Flounder, 4.3%	Fish unspecified, 4.4%
9th	Shellfish dishes in sauce, 2.4%	Seafood soups & casseroles with vegetables, 3.6%	Sea bass, 3.2%	Ocean perch, 3.2%	Salmon, 3.4%	Haddock, 3.9%, Frozen seafood dinners, 3.9%
10th	Frozen seafood dinners, 2.4%	Porgy, 3.6%	Trout, 2.7%	Perch, 3.2%	Catfish, 2.9%	Flounder, 3.3%

Communications with experts in the seafood industry as well as the import/export and productions statistics published by the National Marine Fisheries Service and the Food and Agriculture Organization) indicate the predominant species of fish and shellfish are the various species of tuna, shrimp, and the Alaskan pollock. Superimposed on these broad national trends in fish/shellfish consumption, are regional trends in fish/shellfish consumption. Table 4-45 describes regional popularity of fish species within the United States.

Table 4-45
Regional Popularity of Fish and Shellfish Species

Region	Most Popular Fish Consumed
East Coast	haddock, cod*, flounder, lobster, blue crab, shrimp
South	shrimp, catfish, grouper, red snapper, blue crab
West Coast	salmon, dungeness crab, shrimp, rockfish
Mid-West	Perch, Walleye, Chubs, Multiple Varities of Freshwater Fish

**In the late 1990s, cod has been replaced on menus largely by Alaskan pollock.*

These impressions are supported by descriptions of the best-selling fish/shellfish species in various types of restaurants as shown in Table 4-46 (Seafood Business magazine cited by Johnson, 1997, page 71).

Table 4-46
Popularity of Fish/Shellfish Species in Restaurants

Rank	First	Second	Third
By Region:			
North East	Salmon	Shrimp	Swordfish
South	Shrimp	Salmon	Catfish
Midwest	Salmon	Shrimp	Cod*
West/Pacific	Salmon	Shrimp	Halibut
By Restaurant Style:			
"Fast Food"	Cod*/Shrimp	Clams/Scallops	Tuna
"Dinnerhouse"	Shrimp	Salmon	Lobster
"White Tablecloth"	Salmon	Shrimp	Swordfish
By Overall Sales:			
1996	Shrimp	Salmon	Cod*
1995	Cod*	Shrimp/Salmon	Swordfish
1994	Cod*	Shrimp/Salmon	Swordfish
1993	Cod* (& All Whitefish)	Shrimp	Hoki

Rank	First	Second	Third
1992	Cod* (& All Whitefish)	Shrimp	Crab

**In the late 1990s, cod has been replaced on menus largely by Alaskan pollock.*

Although the species shown in Tables 4-45 and 4-46 are popular regionally, for the United States as a whole, the national statistics indicate major fish consumed are: tuna, shrimp, and Alaskan pollock.

4.2.3.3 Fish and Shellfish Consumption by Children

The NHANES III data were analyzed to determine the species of fish and shellfish consumed by children in the age categories 1-to-5 years, 6-to-11 years, and 12-to-14 years for male and female survey respondents. Specific choices by age groups are shown in Table 4-47. The top four fish dishes for all age categories of children were:

- fish sticks and patties,
- tuna salad and canned tuna,
- shrimp, and
- catfish.

Table 4-47
Frequencies of Various Fish and Shellfish Food Types
for Children Ages 1 to 5 and 6 to 11 Years by Gender
(Source: NHANES III)

Food Type	Frequency of Various Food Types					
	Ages 1-5 Years		Ages 6-11		Ages 12-14	
	Females	Males	Females	Males	Females	Males
Fish Sticks/Patties	23%	21%	23%	25%	21%	21%
Tuna Salad/ Canned Tuna	33%	27%	26%	19%	28%	25%
Shrimp	8%	6%	11%	10%	12%	12%
Catfish	5%	5%	5%	10%	9%	4%
All Other fish and Shellfish	31%	41%	35%	36%	30%	33%
Total	100%	100%	100%	100%	100%	100%

4.2.4 Production Patterns and Mercury Concentrations for Specific Fish and Shellfish Species

Four species of fish are important predictors of methylmercury exposure because of the frequency with which these are consumed by the overall population.

4.2.4.1 Tuna

Although consumption of canned tuna continues to fall (Johnson, 1997), tuna (canned and fresh or frozen) continues to be the most commonly consumed fish based on data from contemporary surveys of food intake by individuals. The mercury concentration of tuna varies with species reflecting variability in fish size and geographic location.

The mean mercury concentration in tuna is 0.206 µg/gram based on data from NMFS. This represents an average for the mean concentrations measured in three types of tuna: albacore tuna (0.264 µg/g), skipjack tuna (0.136 µg/g, and yellowfin tuna (0.218 µg/g). Data cited by U.S. FDA (1978) indicate the following mean (maximum) values in µg/g for various tuna species: tuna, light skipjack, 0.144 (0.385); tuna light yellow, 0.271 (0.870); tuna, white 0.350 (0.904). Cramer (1994) observed that recent U.S. FDA surveys indicated that the mean mercury content of 1973 samples of canned tuna was 0.21 µg/g, whereas a 1990s survey of 245 samples of canned tuna was 0.17 µg/g mercury.

4.2.4.2 Shrimp

Shrimp consumption based on contemporary nationally representative surveys in the United States continues to be a top-ten seafood choice by both adults and children. World shrimp supplies are in excess of 3,000,000 metric tons (Johnson, 1997) with approximately one-sixth of the production grown by aquaculture. This amounts to approximately 500,000 metric tons grown by aquaculture. The United States is a net importer of shrimp with major suppliers (in order of the quantity imported into the United States) Thailand, Ecuador, Mexico, and India (Johnson, 1997).

The overall averaged mercury concentration in marine shrimp reported by the NMFS is 0.047 µg/g. This is an average of the mean concentrations measured in seven types of shrimp: royal red shrimp (0.074 µg/g), white shrimp (0.054 µg/g), brown shrimp; (0.048 µg/g), ocean shrimp (0.053 µg/g), pink shrimp (0.031 µg/g), pink northern shrimp (0.024 µg/g), and Alaska (sidestripe) shrimp (0.042 µg/g). Data cited by U.S. FDA (1978) indicate a mean value of 0.040 with a maximum of 0.440 µg/g.

Shrimp consumed in the United States are predominantly imported from Thailand, Ecuador, and India. The authors of the Report to Congress have not identified data specifically reporting mercury concentrations in shrimp from the countries which are currently the major suppliers of shrimp to the United States.

4.2.4.3 Pollock

The Alaskan pollock dominates the U.S. seafood industry. In 1996, pollock landings totaled 2.6 billion pounds (Johnson, 1997). Pollock is the fish species used in preparation of fish sticks, fish sandwiches served by various “fast food” restaurant franchises in the United States, artificial “crab” or surimi.

The mercury concentration attributed to pollock is 0.15 µg/g based on NMFS data. Data cited by U.S. FDA indicate a mean mercury concentration for pollock of 0.141 (maximum value, 0.96 µg/g).

4.2.4.4 Salmon

Salmon is a highly important fish species based on frequency of consumption of both the canned and fresh product. Species include: chinook, coho, chum, sockeye, and pink. Production has declined in the United States between 1995 and 1996, although the world supply of salmon has continued to grow. Salmon is one of the major fish species grown by aquaculture with production of approximately 50 million pounds per year in the United States.

The mercury content used for salmon was the average of the mean concentrations measured in five types of salmon: pink (0.019 µg/g), chum (0.030 µg/g), coho (0.038 µg/g), sockeye (0.027 µg/g), and chinook (0.063 µg/g). Salmon that is raised by aquaculture based on consumption of corn and soy products may have lower mercury concentrations because of the low mercury concentration of the vegetable products fed to the aquaculture-raised salmon. Data cited by U.S. FDA (1978) indicated a mean value for salmon of 0.040 (maximum 0.201).

4.2.4.5 Catfish

Catfish ranks in the top ten fish produced and consumed. Catfish dominates the aquaculture production in the United States with production of approximately 475 million pounds round (i.e., live) weight. The mercury concentration of freshwater catfish used in the Mercury Study Report to Congress was 0.088 µg/g. Data cited by U.S. FDA (1978) indicate a mean value of 0.146 µg/g (with a maximum value of 0.38 µg/g). As with salmon, catfish raised by aquaculture on vegetable products (e.g., corn and soy) are predicted to have lower mercury concentrations than capture catfish.

4.3 Mercury Concentrations In Fish

Mercury concentrations in marine, estuarine, and freshwater fish were obtained from data bases maintained for marine and estuarine fish and shellfish (National Marine Fisheries Service, 1978) and freshwater fish (Lowe et al., 1985; and Bahnick et al., 1994). These data combined with estimates of fish/shellfish consumption from various dietary surveys form the basis for predicted mercury exposures through fish and shellfish.

4.3.1 National Marine Fisheries Service Data Base

Analyses of total mercury concentrations in marine and estuarine fish and shellfish have been carried out over the past two to three decades. Data describing methylmercury concentrations in marine fish were predominantly based on the National Marine Fisheries' Service (NMFS) data base, the largest publicly available data base on mercury concentrations in marine fish. In the early 1970s, the NMFS conducted testing for total mercury on over 200 seafood species of commercial and recreational interest (Hall et al., 1978). The determination of mercury in fish was based on flameless (cold vapor) atomic absorption spectrophotometry following chemical digestion of the fish sample. These methods were described in Hall et al. (1978).

Although the NMFS data were initially compiled beginning in the 1970s, comparisons of the mercury concentration identified in the NMFS's data base with compliance samples obtained by the U.S. FDA indicate that the NMFS data are appropriate to use in estimating intake of mercury from fish at the national level of data aggregation. Cramer (1994) of the Office of Seafood of the Center for Food Safety and Applied Nutrition of the U.S. FDA reported on *Exposure of U.S. Consumers to Methylmercury from Fish*. He noted that recent information from NMFS indicated that the fish mercury concentrations reported in the 1978 report do not appear to have changed significantly. The U.S. FDA continues to monitor methylmercury concentration in seafood. Cramer (1994) observed that results of recent U.S. FDA surveys indicate results parallel to earlier findings by U.S. FDA and NMFS. To illustrate, Cramer estimated the mean methylmercury content of the 1973 samples of canned tuna at 0.21 µg/g mercury, whereas a recently completed survey of 245 samples of canned tuna was 0.17 µg/g mercury. These data are considered to be comparable, although the small decrease reported between these two studies may reflect increased use in canned tuna of tuna species with slightly lower average methylmercury concentrations. The National Academy of Sciences' National Research Council's Subcommittee on Seafood Safety (1991) also assessed the applicability of the NMFS' 1970s data base to current estimates of mercury concentrations in fish. This subcommittee also concluded that the 1978 data base differed little in mercury concentrations from U.S. FDA compliance samples estimating mercury concentrations in fish.

Assessment of this data base by persons with expertise in analytical chemistry and patterns of mercury contamination of the environment have indicated that temporal patterns in mercury concentrations in fish do not preclude use of this data base in the present risk assessment (US EPA's Science Advisory Board's ad hoc Mercury Subcommittee; Interagency Peer Review Group, External Peer Review Group). One issue that did arise, however, concerned how zero and trace values were entered into calculation of mean mercury concentrations. This has been evaluated statistically through comparison of mean values when different approaches were taken to mathematically calculated means under different assumptions of inclusion of zero and trace values.

The NMFS Report provided data on number of samples, number of nondetects, and mean, standard deviation, minimum and maximum mercury levels (in parts per million wet weight) for 1,333 combinations of fish/shellfish species, variety, location caught, and tissue (Hall et al., 1978). This data base includes 777 fish/shellfish species for which mercury concentration data are provided. This represents 5,707 analyses of fish and shellfish tissues for total mercury, of which 1,467 or 26%, are reported as nondetectable levels. Because the mercury concentration data are used in our analyses at the species level, not at the more detailed species/variety/location/tissue level, the data have been grouped to reflect 35 different fish/shellfish species.

The frequency of nondetectable or "zero" values differs with the mercury concentration. When mean mercury levels are relatively "large", there are few, if any, nondetects, so the methodology employed to handle nondetects is irrelevant. When mean mercury levels are small, there are relatively large numbers of nondetectable values. Because the method of including/excluding nondetectable values in the calculation has the greatest impact only when mercury concentrations are very low, the overall impact on estimated mercury exposure is small.

A statistical assessment of these potential differences was carried out by Westat Corporation (Memo from Robert Clickner, September 26, 1997). A description of the statistical basis for the comparison is shown in Appendix C. To determine the detection limit applicable to the data base, the lowest of all detected analytical values was presumed to be the detection limit. This value is 0.010 µg/g wet weight. The major conclusion of this analysis is that different methods of handling nondetects have negligible impact on the reported mean concentrations. Consequently the mean values as reported by the NMFS will be used in preparing estimates of mercury intake from marine and estuarine fish and shellfish.

Mercury concentration in various fish species are shown in Table 4-48.

Table 4-48
Summary of Mercury Concentrations in Fish Species
(µg Hg/g fresh weight)

Table 4-48 (continued)
Summary of Mercury Concentrations in Fish Species
(µg Hg/g fresh weight)

Data Used by USEPA Mercury Study Report to Congress* 1997		Data Used by US FDA Report on the Chance of U.S. Seafood Consumers Exceeding "The Current Daily Intake for Mercury and Recommended Regulatory Controls" 1978			Data Used by Stern et al. 1996	
Fish Species	**Average (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**	**Maximum (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**
Abalone	0.016	Abalone	0.018	0.120	Not Reported (NR)	
Anchovies	0.047	Anchovies	0.039	0.210	NR	
Bass, Freshwater	Avgs.= 0.157 (Lowe et al., 1985) and 0.38 (Bahnick et al., 1994)	Bass, Striped	0.752	2.000	Bass, freshwater	0.41
Bass, Sea	Not Reported	Bass, Sea	0.157	0.575	Bass, Sea	0.25
Bluefish	Not Reported	Bluefish	0.370	1.255	Bluefish	0.35
Bluegills	0.033	Bluegills	0.259	1.010	NR	
Bonito	Not Reported	Bonito (below 3197)	0.302	0.470	NR	
Bonito	Not Reported	Bonito (above 3197)	0.382	0.740	NR	
Butterfish	Not Reported	Butterfish	0.021	0.190	Butterfish	0.05
Carp, Common	0.093	Carp	0.181	0.540	Catfish, freshwater	0.15
Catfish (channel,large mouth, rock, striped, white)	0.088	Catfish (freshwater)	0.146	0.380	Clams	0.05
Catfish (Marine)	Not Reported	Catfish (Marine)	0.475	1.200	Cod/Scrod	0.15
Clams	0.023	Clams	0.049	0.260	See crab.	
Cod	0.121	Cod	0.125	0.590	Crab	0.15
Crab, King	0.070; Calculations based on 5 species of crab combined at 0.117	Crab, King	0.070	0.240	NR	

Table 4-48 (continued)
Summary of Mercury Concentrations in Fish Species
(µg Hg/g fresh weight)

Data Used by USEPA Mercury Study Report to Congress* 1997		Data Used by US FDA Report on the Chance of U.S. Seafood Consumers Exceeding "The Current Daily Intake for Mercury and Recommended Regulatory Controls" 1978			Data Used by Stern et al. 1996	
Fish Species	**Average (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**	**Maximum (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**
Crab	0.117	Crab, other than King	0.140	0.610	NR	
Crappie (black, white)	0.114	Crappie	0.262	1.390	NR	
Croaker	0.125	Croaker	0.124	0.810	NR	
Dolphin	Not Reported	Dolphin	0.144	0.530	Dolphin (Mahi-mahi)	0.25
Drums, Freshwater	0.117	Drums	0.150	0.800	NR	
Flounders	0.092	Flounders	0.096	0.880	Flounder	0.10
Groupers		Groupers	0.595	2.450	NR	
Haddock	0.089	Haddock	0.109	0.368	Haddock	0.05
Hake	0.145	Hake	0.100	1.100	Hake	0.10
Halibut	0.250	Halibut 4	0.187	1.000	Halibut	0.25
Halibut	0.250	Halibut 3	0.284	1.260	Halibut	0.25
Halibut	0.250	Halibut 2H	0.440	1.460	Halibut	0.25
Halibut	0.250	Halibut 25	0.534	1.430	Halibut	0.25
Herring	0.013	Herring	0.023	0.260	Herring	0.05
Kingfish	0.100	Kingfish	0.078	0.330	Kingfish	0.05
Lobster	0.232	Lobster, Northern 11	0.339	1.603	Lobster	0.25
Lobster	0.232	Lobster Northern 10	0.509	2.310	Lobster	0.25
Lobster Spiny	0.232; Includes spiny (Pacific) lobster=0.210	Lobster,Spin y	0.113	0.370	Lobster	0.25

Table 4-48 (continued)
Summary of Mercury Concentrations in Fish Species
(µg Hg/g fresh weight)

Data Used by USEPA Mercury Study Report to Congress* 1997		Data Used by US FDA Report on the Chance of U.S. Seafood Consumers Exceeding "The Current Daily Intake for Mercury and Recommended Regulatory Controls" 1978			Data Used by Stern et al. 1996	
Fish Species	**Average (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**	**Maximum (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**
Mackerel	0.081; Averaged Chub = 0.081; Atlantic= 0.025; Jack=0.138	Mackerel, Atlantic	0.048	0.190	Mackerel	0.28
Mackerel	0.081	Mackerel, Jack	0.267	0.510	Mackerel	0.28
Mackerel	0.081	Mackerel, King (Gulf)	0.823	2.730	Mackerel	0.28
Mackerel	0.081	Mackerel, King (other)	1.128	2.900	Mackerel	0.28
Mackerel	0.081	Mackerel, Spanish 16	0.542	2.470	Mackerel	0.28
Mackerel	0.081	Mackerel, Spanish 10	0.825	1.605	Mackerel	0.28
Mullet	0.009	Mullet	0.016	0.280	Mullet	0.05
Oysters	0.023	Oysters	0.027	0.460	NR	
Perch, White and Yellow	0.110	Perch, Freshwater	0.290	0.880	Perch	0.18
Perch, Ocean	0.116	Perch, Marine	0.133	0.590	NR	
Pike, Northern	0.310 0.127	Pike	0.810	1.710	NR	
Pollock	0.150	Pollock	0.141	0.960	NR	
Pompano	0.104	Pompano	0.104	8.420	NR	
Rockfish	Not Reported	Rockfish	0.340	0.930	NR	
Sablefish	Not Reported	Sablefish	0.201	0.700	NR	
Salmon	0.035	Salmon	0.040	0.210	Salmon	0.05
Scallops	0.042	Scallops	0.058	0.220	NR	
Scup	Not Reported	Scup	0.106	0.520	NR	

Table 4-48 (continued)
Summary of Mercury Concentrations in Fish Species
(μg Hg/g fresh weight)

Data Used by USEPA Mercury Study Report to Congress* 1997		Data Used by US FDA Report on the Chance of U.S. Seafood Consumers Exceeding "The Current Daily Intake for Mercury and Recommended Regulatory Controls" 1978			Data Used by Stern et al. 1996	
Fish Species	**Average (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**	**Maximum (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**
Sharks	1.327	Sharks	1.244	4.528	Shark	1.11
Shrimp	0.047	Shrimp	0.040	0.440	Shrimp	0.11
Smelt	0.100	Smelt	0.016	0.058	Smelts	0.05
Snapper	0.25	Snapper,Red	0.454	2.170	Snapper	0.31
Snapper	0.25	Snapper, Other	0.362	1.840	Snapper	0.31
Snook	Not Reported	Snook	0.701	1.640	NR	
Spot	Not Reported	Spot	0.041	0.180	Spotfish	0.05
Squid	0.026	Squid and Octopi	0.031	0.400	Squid	0.05
Octopi	0.029	Squid and Octopi	0.031	0.400	NR	
Sunfish	Not Reported	Sunfish	0.312	1.200	NR	
Swordfish	0.95	Swordfish	1.218	2.720	Swordfish	0.93
Tillefish	Not Reported	Tillefish	1.607	3.730	NR	
Trout,	0.149	Trout, Freshwater	0.417	1.220	Trout	0.05
Trout	0.149	Trout, Marine	0.212	1.190	Trout	0.05
Tuna	0.206; Averaged: Tuna, light skipjack=0.13 6Tuna,light yellow=0.218; Albacore=0.2 64	Tuna, Light Skipjack	0.144	0.385	Tuna, fresh	0.17
Tuna	0.206	Tuna, Light Yellow	0.271	0.870	Tuna, fresh	0.17
Tuna	0.206	Tuna, White	0.350	0.904	Tuna, fresh	0.17
Whitefish	Not Reported	Whitefish	0.054	0.230	Whitefish	0.04

Table 4-48 (continued)
Summary of Mercury Concentrations in Fish Species
(µg Hg/g fresh weight)

Data Used by USEPA Mercury Study Report to Congress* 1997		Data Used by US FDA Report on the Chance of U.S. Seafood Consumers Exceeding "The Current Daily Intake for Mercury and Recommended Regulatory Controls" 1978			Data Used by Stern et al. 1996	
Fish Species	**Average (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**	**Maximum (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**
Other finfish		Other finfish	0.287	1.020	Finfish, other	0.17
Other shellfish	Not Reported				Shellfish, other	0.12
Fish Species (Freshwater) Not Reported by FDA, 1978						
Bloater	0.0.93					
Smallmouth Buffalo	0.096					
Northern Squawfish	0.33					
Sauger	0.23					
Sucker	0.114 (Lowe et al., 1985; 0.167 (Bahnick et al., 1994).					
Walleye	0.100 (Lowe et al., 1985) and 0.52 (Bahnick et al., 1994).					
Trout (brown, lake, rainbow)	0.149 (Lowe et al., 1985) and 0.14 (Bahnick et al., 1994 for brown trout).					
Fish Species Reported by the State of New Jersey and Not Reported by EPA or FDA						
Blowfish						0.05
Orange roughy						0.5
Sole						0.12
Weakfish						0.15
Porgy						0.55

Table 4-48 (continued)
Summary of Mercury Concentrations in Fish Species
(µg Hg/g fresh weight)

Data Used by USEPA Mercury Study Report to Congress* 1997		Data Used by US FDA Report on the Chance of U.S. Seafood Consumers Exceeding "The Current Daily Intake for Mercury and Recommended Regulatory Controls" 1978			Data Used by Stern et al. 1996	
Fish Species	**Average (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**	**Maximum (μg Hg/g)**	**Fish Species**	**Average (μg Hg/g)**
Blackfish						0.25
Whiting						0.05
Turbot						0.10
Sardines						0.05
Tilapia						0.05

* *See Sections 4.3.1 and 4.3.2 for data on marine species, and Section 4.3.3 for data on freshwater fish.*

4.3.2 Mercury Concentrations in Marine Fish

Data supplied by NMFS give the mercury concentrations in fresh weight of fish muscle of numerous marine fish, shellfish, and other molluscan/crustacean species shown in Table 4-49, 4-50 and 4-51.

Table 4-49
Mercury Concentrations in Marine Finfish

Fish	Mercury Concentration (μg/g, wet weight)	Source of Data
Anchovy[1]	0.047	NMFS
Barracuda, Pacific[2]	0.177	NMFS
Cod[3]	0.121	NMFS
Croaker, Atlantic	0.125	NMFS
Eel, American	0.213	NMFS
Flounder[4]	0.092	NMFS
Haddock	0.089	NMFS
Hake[5]	0.145	NMFS
Halibut[6]	0.25	NMFS
Herring[7]	0.013	NMFS
Kingfish[8]	0.10	NMFS

Table 4-49 (continued)
Mercury Concentrations in Marine Finfish

Fish	Mercury Concentration (μg/g, wet weight)	Source of Data
Mackerel[9]	0.081	NMFS
Mullet[10]	0.009	NMFS
Ocean Perch[11]	0.116	NMFS
Pollack	0.15	NMFS
Pompano	0.104	NMFS
Porgy	0.522	NMFS
Ray	0.176	NMFS
Salmon[12]	0.035	NMFS
Sardines[13]	0.1	NMFS
Sea Bass	0.135	NMFS
Shark[14]	1.327	NMFS
Skate[15]	0.176	NMFS
Smelt, Rainbow	0.1	NMFS
Snapper[16]	0.25	NMFS
Sturgeon[17]	0.235	NMFS
Swordfish	0.95	FDA Compliance Testing
Tuna[18]	0.206	NMFS
Whiting (silver hake)	0.041	NMFS

[1] This is the average of NMFS mean mercury concentrations for both striped anchovy (0.082 μg/g) and northern anchovy (0.010 μg/g).
[2] USDA data base specified the consumption of the Pacific barracuda and not the Atlantic barracuda.
[3] The mercury content for cod is the average of the mean concentrations in Atlantic cod (0.114 μg/g and the Pacific cod (0.127 μg/g).
[4] The mercury content for flounder is the average of the mean concentrations measured in 9 types of flounder: Gulf (0.147 μg/g), summer (0.127 μg/g), southern (0.078 μg/g), four-spot (0.090 μg/g), windowpane (0.151 μg/g), arrowtooth (0.020 μg/g), witch (0.083 μg/g), yellowtail (0.067 μg/g), and winter (0.066 μg/g).
[5] The mercury content for hake is the average of the mean concentrations measured in 6 types of hake: silver (0.041 μg/g), Pacific (0.091 μg/g), spotted (0.042 μg/g), red (0.076 μg/g), white (0.112 μg/g), and blue (0.405 μg/g).
[6] The mercury content for halibut is the average of the mean concentrations measured in 3 types of halibut: Greenland, Atlantic, and Pacific.
[7] The mercury content for herring is the average of the mean concentrations measured in 4 types of herring: blueback (0.0 μg/g), Atlantic (0.012 μg/g), Pacific (0.030 μg/g), and round (0.008 μg/g).
[8] The mercury content for kingfish is the average of the mean concentrations measured in 3 types of kingfish: southern, Gulf, and northern.
[9] The mercury content for mackerel is the average of the mean concentrations measured in 3 types of mackerel: jack (0.138 μg/g), chub (0.081 μg/g), and Atlantic (0.025 μg/g).
[10] The mercury content for mullet is the average of the mean concentrations measured in 2 types of mullet: striped (0.011 μg/g) and silver (0.007 μg/g).
[11] The mercury content for ocean perch is the average of the mean concentrations measured in 2 types of ocean perch: Pacific (0.083 μg/g) and redfish (0.149 μg/g).

[12] The mercury content for salmon is the average of the mean concentrations measured in 5 types of salmon: pink (0.019 μg/g), chum (0.030 μg/g), coho (0.038 μg/g), sockeye (0.027 μg/g), and chinook (0.063 μg/g).
[13] Sardines were estimated from mercury concentrations in small Atlantic herring.
[14] The mercury content for shark is the average of the mean concentrations measured in 9 types of shark: spiny dogfish (0.607 μg/g), (unclassified) dogfish (0.477 μg/g), smooth dogfish (0.991 μg/g), scalloped hammerhead (2.088 μg/g), smooth hammerhead (2.663 μg/g), shortfin mako (2.539 μg/g), blacktip shark (0.703 μg/g), sandbar shark (1.397 μg/g), and thresher shark (0.481 μg/g).
[15] The mercury content for skate is the average of the mean concentrations measured in 3 types of skate: thorny skate (0.200 μg/g), little skate 0.135 μg/g) and the winter skate (0.193 μg/g).
[16] The mercury content for snapper is the average of the mean concentrations measured in types of snapper:
[17] The mercury content for sturgeon is the average of the mean concentrations measured in 2 types of sturgeon:green sturgeon (0.218 μg/g) and white sturgeon (0.251 μg/g).
[18] The mercury content for tuna is the average of the mean concentrations measured in 3 types of tuna: albacore tuna (0.264 μg/g), skipjack tuna (0.136 μg/g) and yellowfin tuna (0.218 μg/g).

Table 4-50
Mercury Concentrations in Marine Shellfish

Shellfish	Mercury Concentration (μg/g, wet weight)	Source of Data
Abalone[1]	0.016	NMFS
Clam[2]	0.023	NMFS
Crab[3]	0.117	NMFS
Lobster[4]	0.232	NMFS
Oysters[5]	0.023	NMFS
Scallop[6]	0.042	NMFS
Shrimp[7]	0.047	NMFS

[1] The mercury content for abalone is the average of the mean concentrations measured in 2 types of abalone: green abalone (0.011 μg/g) and red abalone (0.021 μg/g).
[2] The mercury content for clam is the average of the mean concentrations measured in 4 types of clam: hard (or quahog) clam (0.034 μg/g), Pacific littleneck clam (0 μg/g), soft clam (0.027 μg/g), and geoduck clam (0.032 μg/g).
[3] The mercury content for crab is the average of the mean concentrations measured in 5 types of crab: blue crab (0.140 μg/g), dungeness crab (0.183 μg/g), king crab (0.070 μg/g), tanner crab (C.opilio) (0.088 μg/g), and tanner crab (C.bairdi) (0.102 μg/g).
[4] The mercury content for lobster is the average of the mean concentrations measured in 3 types of lobster: spiny (Atlantic) lobster (0.108 μg/g), spiny (Pacific) lobster (0.210 μg/g) and northern (American) lobster (0.378 μg/g).
[5] The mercury content for oyster is the average of the mean concentrations measured in 2 types of oyster: eastern oyster (0.022 μg/g) and Pacific (giant) oyster (0.023 μg/g).
[6] The mercury content for scallop is the average of the mean concentrations measured in 4 types of scallop: sea (smooth) scallop (0.101 μg/g), Atlantic Bay scallop (0.038 μg/g), calico scallop (0.026 μg/g), and pink scallop (0.004 μg/g).
[7] The mercury content for shrimp is the average of the mean concentrations measured in 7 types of shrimp: royal red shrimp (0.074 μg/g), white shrimp (0.054 μg/g), brown shrimp (0.048 μg/g), ocean shrimp (0.053 μg/g), pink shrimp (0.031 μg/g), pink northern shrimp (0.024 μg/g) and Alaska (sidestripe) shrimp (0.042 μg/g).

Table 4-51
Mercury Concentrations in Marine Molluscan Cephalopods

Cephalopod	Mercury Concentration (μg/g wet wt.)	Source of Data
Octopus	0.029	NMFS
Squid[1]	0.026	NMFS

[1] The mercury content for squid is the average of the mean concentrations measured in 3 types of squid: Atlantic longfinned squid (0.025 μg/g), short-finned squid (0.034 μg/g), and Pacific squid (0.018 μg/g)

4.3.3 Freshwater Fish Mercury Data Base

Freshwater fish mercury concentrations were reported by Lowe et al. (1985) and by Bahnick et al. (1994). Details of their analyses are presented separately from those on marine fish. Lowe et al. (1985) used flameless cold vapor technique absorption spectrophotometry in their analyses. Mean recovery for mercury averaged 96.6±14.4 (SD) based on 72 analyses of spiked samples. Duplicate analyses showed a percent difference of 10.6±14.4 (SD) based on 51 duplicates. Values were reported as the geometric means, minimum, and maximum of elemental mercury concentrations during 1978 to 1979 and during 1980 to 1981. The limit of detection for mercury was 0.01 µg/g wet weight. Standard reference materials were included and resulted of their analysis are shown in Table 4-52.

Table 4-52
Analyses of Mercury Standard Reference Materials Used by Lowe et al. (1985) in Support of Analyses of Freshwater Fish

Mercury Reference Material	Certified Concentration Range (µg/g)	Number of Samples Analyzed	Measured Concentrations (µg/g: mean ± 1SD)
bovine liver	0.016±0.002	53	0.021±0.007
oyster	0.057±0.015	14	0.050±0.005
tuna	0.95±0.10	32	0.86±0.07

Values of 0.01 µg mercury/g fish tissue are routinely reported in this data base. Samples were handled as individual fish. Mercury residues were reported for all species and all locations. The geometric mean mercury concentrations for all freshwater fish species was 0.11 µg/g in 1978 to 1979 and 0.11 µg/g in 1980-1981. The minimum value for both time periods was 0.01 µg/g and the maximum value was 1.10 µg/g in 1978-1979 and 0.77 µg/g in 1980-1981. The 85th percentile value in both time periods was 0.18 µg/g.

Bahnick et al. (1994) used cold mercury vapor flameless atomic absorption and detected mercury in 92.2% of the fish sampled. Non-detects were reported as a zero value and averaged as zeros. Two separate detection limits were reported. Prior to 1990, 465 samples were analyzed using a method having a detection limit of 0.05 µg/g. Modification of the method for the final 195 samples produced a detection limit of 0.0013 µg/g. The estimated standard deviation for replicate samples was 0.047 µg/g in the concentration range of 0.08 to 1.79 µg/g. Analysis of EPA reference fish having a reported experimental mean value of 2.52 µg/g (s=0.64) produced a mean value for mercury of 2.87 (s=0.08) in this study. The mean value for the overall data set for 669 samples was 0.26 µg/g. Mercury was detected in fish collected from the 374 sites.

Because mercury emissions from the ambient sources considered in the current Report to Congress have different impacts on global and local deposition, it was considered important to separate fish species by habitat. Specifically, global mercury cycling was judged to have its greatest impact on marine species, whereas local deposition was considered more likely to affect estuarine and freshwater fish and shellfish species. The species were classified as shown in Table 4-14 on a classification system described by Jacobs et al. (in press).

Central tendency estimates of seafood mercury concentrations were utilized in the report. This seems appropriate since commercial seafood is widely distributed across the United States (*Seafood Safety*, 1991). The source of a particular fish purchase is generally not noted by the consumer (e.g., canned tuna). As a result, a randomness and averaging may be achieved. Additionally, only common names of commercial seafood were utilized; specific species which could be considered to be that type of fish were included in the central tendency estimate. Again, typical consumers were assumed to generally not be aware of the species of fish they were consuming, rather just the type.

As noted above, there are other estimates of mercury concentrations in seafood. After the analysis of mercury exposure from seafood was completed for this Report, two other databases were obtained: U.S. FDA and Stern et al. (1996). These data are presented in Table 4-51 for comparison with those data used for this analysis.

4.3.4 Mercury Concentrations In Freshwater Fish

Estimation of average mercury concentrations in freshwater finfish from across the United States required a compilation of measurements of fish mercury concentrations from randomly selected U.S. water bodies. A large number of sources of mercury concentrations in fish were not used in this part of the assessment. Mercury concentrations in fish have been analyzed for a number of years in many local or regional water bodies in the United States; several of these studies are detailed in this Report. Data described in this body of literature are a collection of individual studies which characterize mercury concentrations in fish from specific geographic regions such as individual water bodies or in individual states. Many of the studies were initiated because of a problem, perceived or otherwise, with mercury concentrations in the fish or the water body. Thus, the sample presented by a compilation of these data may be biased toward the high-end of the distribution of mercury concentrations in freshwater fish. Additionally, the methods varied from study to study, and there is no way of determining the consistency of the reported data from study to study.

Two studies, more national in scope, are thought to provide a more complete picture of mercury concentrations in U.S. freshwater finfish populations: "National Contaminant Biomonitoring Program: Concentrations of Seven Elements in Freshwater Fish, 1978-1981" by Lowe et al. (1985) and "A National Study of Chemical Residues in Fish" conducted by U.S. EPA (1992) and also reported in Bahnick et al. (1994).

Lowe et al. (1985) reported mercury concentrations in fish from the National Contaminant Biomonitoring Program. The freshwater fish data were collected between 1978-1981 at 112 stations located across the United States. Mercury was measured by a flameless cold vapor technique, and the detection limit was 0.01 µg/g wet weight. Most of the sampled fish were taken from rivers (93 of the 112 sample sites were rivers); the other 19 sites included larger lakes, canals, and streams. Fish weights and lengths were consistently recorded. A wide variety of types of fishes were sampled: most commonly carp, large mouth bass and white sucker. The geometric mean mercury concentration of all sampled fish was 0.11 µg/g wet weight; the minimum and maximum concentrations reported were 0.01 and 0.77 µg/g wet weight, respectively. The highest reported mercury concentrations (0.77 µg/g wet weight) occurred in the northern squawfish of the Columbia River. See Table 4-53 for mean mercury concentrations by fish species.

Table 4-53
Freshwater Fish Mercury Concentrations from Lowe et al., (1985)

Species	Mean Mercury Concentration µg/g (fresh weight)
Bass	0.157
Bloater	0.093
Bluegill	0.033
Smallmouth Buffalo	0.096
Carp, Common	0.093
Catfish (channel, largemouth, rock, striped, white)	0.088
Crappie (black, white)	0.114
Fresh-water Drum	0.117
Northern Squawfish	0.33
Northern Pike	0.127
Perch (white and yellow)	0.11
Sauger	0.23
Sucker (bridgelip, carpsucker, klamath, largescale, longnose, rivercarpsucker, tahoe)	0.114
Trout (brown, lake, rainbow)	0.149
Walleye	0.100
Mean of all measured fish	0.11

"A National Study of Chemical Residues in Fish" was conducted by U.S. EPA (1992) and also reported by Bahnick et al. (1994). In this study mercury concentrations in fish tissue were analyzed. Five bottom feeders (e.g., carp) and five game fish (e.g., bass) were sampled at each of the 314 sampling sites in the United States. The sites were selected based on proximity to either point or non-point pollution sources. Thirty-five "remote" sites among the 314 were included to provide background pollutant concentrations. The study primarily targeted sites that were expected to be impacted by increased dioxin levels. The point sources proximate to sites of fish collection included the following: pulp and paper mills, Superfund sites, publicly owned treatment works and other industrial sites. Data describing fish age, weight, and sex were not consistently collected. Whole body mercury concentrations were determined for bottom feeders and mercury concentrations in fillets were analyzed for the game fish. Total mercury levels were analyzed using flameless atomic absorption; the reported detection limits were 0.05 µg/g early in the study and 0.0013 µg/g as analytical technique improved later in the analysis. Mercury was detected in fish at 92% of the sample sites. The maximum mercury level detected was 1.8 µg/g, and the mean across all fish and all sites was 0.26 µg/g. The highest measurements occurred in walleye, large mouth bass and carp. The mercury concentrations in fish around publicly owned treatment works were highest of all point source data; the median value measured were 0.61 µg/g. Paper mills were located near many of the sites where mercury-laden fish was detected. Table 4-54 contains the mean mercury concentrations of the species collected by Bahnick et al. (1994).

Both the studies reported by Lowe et al. (1985) and by Bahnick et al. (1994) appear to be systematic, national collections of fish pollutant concentration data. Clearly, higher mercury concentrations in fish have been detected in other analyses, and the values obtained in these studies should be interpreted as a rough approximation of the mean concentrations in freshwater finfishes. As indicated in the range of data presented in Tables 4-53 and 4-54, as well as the aforementioned Tables in Chapter 2, wide variations are expected in data on mercury concentrations in freshwater fish.

The mean mercury concentrations in all fish sampled vary by a factor of two between the studies. The mean mercury concentration reported by Lowe et al.(1985) was 0.11 µg/g, whereas the mean mercury concentration reported by Bahnick et al. (1994) was 0.26 µg/g. This difference can be extended to the highest reported mean concentrations in fish species. Note that the average mercury concentrations in bass and walleye reported by Bahnick's data are higher than the northern squawfish, which is the species with the highest mean concentration of mercury identified by Lowe et al. (1985).

The bases for these differences in methylmercury concentrations are not immediately obvious. The trophic positions of the species sampled, the sizes of the fish, or ages of fish sampled could significantly increase or decrease the reported mean mercury concentration. Older and larger fish, which occupy higher trophic positions in the aquatic food chain, would, all other factors being equal, be expected to have higher mercury concentrations. The sources of the fish also influence fish mercury concentrations. Most of the fish obtained by Lowe et al. (1985) were from rivers. The fate and transport of mercury in river systems is less well characterized than in small lakes. Most of the data collected by Bahnick et al. (1994) were collected with a bias toward more contaminated/industrialized sites, although not sites specifically contaminated with mercury. It could be that there is more mercury available to the aquatic food chains at the sites reported by Bahnick et al. (1994). Finally, the increase in the more recent data as reported in Bahnick et al. (1994) could be the result of temporal increases in mercury concentrations.

There is a degree of uncertainty in the mercury concentrations selected for this assessment. This uncertainty reflects both the adequacy of the sampling protocol for this application and the known variability in fish body burden. The variability in these data is as broad as the range of reported concentrations, which extends from non-detect (below 0.01 µg/g wet weight) up to 9 µg/g wet weight. Where possible, when specific freshwater fish species are described in the USDA 3-day consumption studies, the mean methylmercury concentration for that particular species was derived in two separate calculations based on the data on methylmercury concentration in the fish reported by Lowe et al. (1985) and by Bahnick et al. (1994).

Data for mean mercury concentration in freshwater fish from Bahnick et al. (1994) were combined with the U.S. consumption rates for freshwater fish from the CSFII 89-91, CSFII 1994, CSFII 1995, and NHANES III to estimate methylmercury intakes for the population. The concentrations in the fish utilized are shown in Table 4-54. The exposure estimates for freshwater fin fish consumption are found in Table 4-55. Bahnick et al. (1994) freshwater fish concentration data were utilized, along with data on mercury concentrations in marine fish and shellfish (Tables 4-48, 4-49, 4-50) to calculate total exposure, for general U.S. population, to mercury through consumption of fish and shellfish (shown in Table 4-55).

Some species of freshwater fishes were not sampled by Bahnick et al. (1994), and some respondents in the USDA CSFII 89-91 survey did not identify the type of freshwater fish consumed. In these situations, it was assumed that the fish consumed contained 0.26 µg methylmercury/g, which is the average of all sampled fish Bahnick et al. (1994). It is important to note that the freshwater fish data are for wild populations not farm-raised fish.

Table 4-54
Mercury Concentrations in Freshwater Fish
U.S. EPA (1992) and Bahnick et al. (1994)

Freshwater Fish	Average Mercury Concentration (µg/g, wet weight)
Carp	0.11
Sucker[1]	0.167
Catfish, Channel and Flathead	0.16
Bass[2]	0.38
Walleye	0.52
Northern Pike	0.31
Crappie	0.22
Brown Trout	0.14
Mean All Fish Sampled	0.26

[1] The value presented is the mean of the average concentrations found in three types of sucker fish (white, redhorse and spotter).
[2] The value presented is the mean of the average concentrations found in three types of bass (white, largemouth and smallmouth).

4.3.5 Calculation of Mercury Concentrations in Fish Dishes

To estimate the mercury intake from fish and fish dishes reported as consumed by respondents in the CSFII surveys and NHANES III survey, several steps were taken. Using the Recipe File available from USDA, the fish species for a particular reported food was identified. The average mercury concentration in fish tissue on a fresh (or wet) weight basis was identified using the NMFS data or the data reported by Bahnick et al. (1994). The food intake of the U.S. population includes a large number of components of aquatic origin. A few of these appear not to have been analyzed for mercury concentrations. Methylmercury concentration data were not available for some infrequently consumed food items; e.g., turtle, roe or jelly fish. Data on the quantity of fish present in commercially prepared soups were also not available and were excluded from the analysis.

Physical changes occur to a food when it is processed and/or cooked. The NMFS and Bahnick et al. (1994) data bases were used to estimate mercury intake report mercury concentrations on a µg mercury per gram of fresh tissue basis. Earlier research (Bloom, 1992) indicated that over 90% of mercury present in fish and shellfish is chemically speciated as methylmercury which is bound to protein in fish tissue. Morgan et al. (1994) indicated that over 90% of mercury present in fish and shellfish is chemically speciated as methylmercury. Consequently the quantity of methylmercury present in the fish tissue in the raw state will remain in the cooked or processed fish. In cooking or processing raw fish, there is typically a reduction in the percent moisture in the food. Thus, mercury concentration data were recalculated to reflect the loss of moisture during food processing, as well as retention of methylmercury in the remaining lowered-moisture content fish tissues. Standard estimates of cooking/processing-related weight reductions were provided by Dr. Betty Perloff and Dr. Jacob Exler, experts in the USDA recipe file and in USDA's food composition. Percent moisture lost for baked or broiled fish was 25%. Fried fish products lose weight through loss of moisture but add weight from fat added during frying for a total weight loss of minus 12%. The percent moisture in fish that were dried, pickled or smoked was identified for individual fish species (e.g., herring, cod, trout, etc.) from USDA handbooks of food composition. Information on the percent moisture in the raw, and in the dried, smoked or pickled fish was obtained. The methylmercury concentration in the fish was recalculated to reflect the increased methylmercury concentration of the fish as the percent moisture decreased in the drying, pickling or smoking process.

The mean mercury concentrations for all fish from Lowe et al. (1985) and Bahnick et al. (1994) were combined with the freshwater fish consumption data to estimate a range of exposure from total fish consumption. Given the human fish consumption rates and the differences between the mercury concentrations in the two data sets, it is important to use data from both studies of mercury exposures to assess mean concentrations in fish. For purposes of comparison both sets of data were utilized to illustrate the predicted methylmercury exposure. For this comparison, the average mercury concentrations for fish in the Lowe and the Bahnick data were analyzed separately by combining the freshwater fish data with the data in Tables 4-48 through 4-50. The bodyweight data and the freshwater fish consumption rates were obtained from Table 4-12. Exposure to methylmercury based on an assumption of 0.11 µg methylmercury/g fish tissue (wet weight) (Lowe et al., 1985). These values are estimated on a body weight basis. Tables 4-53 and 4-54 were developed using the mean data on mercury concentrations for all fishes sampled for these two studies.

Human mercury intake from fish was estimated by combining data on mercury concentration in fish species with the reported quantities and types of fish species reported as consumed by "users" in the national food consumption surveys. The mercury concentrations in the consumed fish reported by the national surveys were estimated using data on mercury concentration in fish expressed as micrograms of mercury per gram fresh-weight of fish tissue.

The CSFII 89-91, CSFII 1994, and CSFII 1995 are three of the USDA's food consumption surveys. An additional nationally-based food consumption survey is the third National Health and Nutrition Examination Survey. The food items reported by individuals interviewed in these surveys are identified by 7-digit food codes. The USDA has developed a recipe file identifying the primary components that make up the food or dish reported "as Eaten" by a survey respondent. The total weight of a fish-containing food is typically not 100% fish. The food code specifies a preparation method and gives additional ingredients used in preparation of the dish. For example, in the Recipe File "Fish, floured or breaded, fried" contains 84% fish, by weight. Fish dishes contained a wide range of fish; from approximately 5% for a frozen "shrimp chow mein dinner with egg roll and peppers" to 100% for fish consumed raw, such as raw shark.

4.4 Intake of Methylmercury from Fish/fish Dishes

Estimates of methylmercury intake from fish and shellfish have been made based on dietary survey data from the nationally representative surveys (CSFII 89-91, CSFII 94, CSFII 95, and NHANES III). Projected month-long estimates of fish/shellfish intake and mercury exposure have been developed from the NHANES III frequency of fish consumption data using data from the adult participants in NHANES III and the 24-hour recall data from children and adults in NHANES III. These month-long projections are considered to be the descriptions of mercury exposure from fish and shellfish that are most relevant to the health endpoint used as the basis for the RfD; i.e. developmental deficits in children following maternal exposure to methylmercury. Based on input from the interagency review a determination has been made that comparison of 24-hour "per user" data is generally inappropriate and will not be done except when describing subpopulations who eat fish/shellfish almost every day.

4.4.1 Intakes "per User" and "per Capita"

The data from major nationally based surveys of the general population are from CSFII 89-91, CSFII 1994, CSFII 1995, and NHANES III conducted between 1988 and 1994. CSFII 89-91 obtained 3-days of dietary history based on 24-hour recall interviews. CSFII 1994 and CSFII 1995 obtained two days of dietary history also obtained by 24-hour recall interview techniques. These two days of dietary recalls were not necessarily sequential days. Interviewers in NHANES III obtained the respondents' estimate of the number of times per day, per week, and per months the respondent consumed fish/shellfish over the past 12-month period. These data were obtained only for persons 12 years of age and older. In addition, recall data on fish/shellfish consumption were obtained on the same respondents as were questionnaire responses of the frequency of food consumption. These recall data cover the 24-hour period prior to the interview.

The number and percent of respondents reporting consumption of fish and/or shellfish in these surveys in shown in Tables 4-55 to 4-57. Intake data can be expressed on a "per capita" basis which reports the statistics calculated for all survey participants whether or not they reported consuming fish and/or shellfish during the recall period. By contrast, "per user" statistics are calculated for only those individuals who reported consuming fish and/or shellfish during the recall periods. The percent of survey respondents who reported consuming fish and/or shellfish on one 24-hour recall ranged from 11.3 to 12.9% in the nationally-based contemporary food consumption surveys (Table 4-54).

Table 4-55
CSFII 89-91 Number of Respondents - All Age Groups

	Ages 14 and Younger	Ages 15 through 45	Ages 46 and Older	Total
Total	2893	4968	3545	11,706
Fish Consumers	720	1510	1384	3614

Table 4-56
CSFII 89-91 Adult Respondents

Gender	Ages 15 to 45 Years	Ages 46 Years and Older	Total for All Age Groups
Males	2131	1537	3668
Females	2837	2308	5145
Respondents Reporting Fish Consumption			
Gender	**Ages 15 to 45 Years**	**Ages 46 Years and Older**	**Total for All Age Groups**
Males	646	556	1202
Females	864	828	1692
Total	1510	1384	2894

Table 4-57
Contemporary Dietary Surveys — 1990s
General U.S. Population

Survey	Total Number of Subjects	Number Reporting Fish/shellfish Consumption	Percent Consuming Fish/shellfish
NHANES III	29,989	3864	12.9
CSFII 94 - *Day 1*	5,296	598	11.3
CSFII 94 - *Day 2*	5,293	596	11.3
CSFII 95 - *Day 1*	5063	601	11.9
CSFII 95 - *Day 2*	5062	620	12.2

4.4.1.1 "Per Capita" Consumption

"Per capita" data for CSFII 89-91 are shown in Table 4-58. Data in CSFII 89-91 reflect averages calculated from three days of 24-hour recall data. Data for the more-recently conducted national surveys are shown in Table 4-59. These data were obtained by interview and describe fish/shellfish consumption in the previous 24-hour period. Interviewers describe two 24-hour recalls per respondent.

Table 4-58
Per Capita Fish/Shellfish Consumption (gms/day) and
Mercury Exposure (µg/kg body weight/day) From CSFII 89-91
Based on Average of Three 24-Hour Recalls

	25th	50th	75th	95th	Maximum
Fish/shellfish Consumption	Zero	Zero	16	73	461
Mercury Exposure	Zero	Zero	0.04	0.24	2.76

Table 4-59
Per Capita Fish/Shellfish Consumption
Based on Individual Days of 24-Hour Recall Data
General U.S. Population Surveys — 1990s

Survey	10th	50th	90th	95th	Maximum
CSFII 94 - Day 1	Zero	Zero	32 0.03	85 0.13	457 3.76
CSFII 94 - Day 2	Zero	Zero	37 0.03	85 0.14	606 4.03
CSFII 95 - Day 1	Zero	Zero	43 0.04	105 0.13	960 5.93
CSFII 95 - Day 2	Zero	Zero	43 0.05	98 0.17	1084 2.63
NHANES III	Zero	Zero	56 0.08	114 0.19	1260 6.96

4.4.1.2 "Per User" Consumption

If statistics are calculated only on those individuals who reported consuming fish and/or shellfish during the recall period "per user" values are calculated. Data from the average (i.e., mean) of three days of 24-hour recalls reported in the CSFII 1989-1991 survey are shown in Table 4-60. Data for the individual two days recorded in CSFII 1994 and in CSFII 1995, and for the single day's 24-hour recall in NHANES III are shown in Table 4-61.

Table 4-60
Per User Fish/Shellfish Consumption (grams per day) and Mercury Exposure (µg/kg bw/day) Based on Average of Three 24-Hour Recalls — CSFII 89-91

	25th	50th	75th	95th	Maximum
Fish/shellfish Consumption	19	32	57	117	461
Mercury Exposure	0.04	0.09	0.18	0.45	2.76

Table 4-61
"Per User" Intake of Fish and Shellfish (gms/day) and Exposure to Mercury (µg Hg/kg bw/day) Among Individuals Reporting Consumption, Based on Individual Day Recall Data

Study	10th	50th	90th	95th	Maximum
CSFII 94 - Day 1 n=598	28 0.02	76 0.11	186 0.43	252 0.65	458 3.76
CSFII 94 - Day 2 n=596	26 0.03	74 0.11	200 0.40	282 0.65	606 1.03
CSFII 95 - Day 1 n=601	28 0.03	84 0.10	197 0.42	261 0.61	960 5.93
CSFII 95 - Day 2 n = 620	24 0.03	79 0.12	216 0.47	285 0.64	1084 2.63
NHANES III n=3,864	22 0.01	73 0.11	242 0.44	336 0.63	1260 6.95

4.4.2 Methylmercury Intake from Fish and Shellfish among Women of Child-bearing Age and Children

Subgroups at increased risk of exposure and/or toxic effects of mercury among the general population include women of childbearing age and children. Exposures to women of childbearing age are of particular interest because methylmercury is a developmental toxin (Tables 4-62 and 4-63).

Table 4-62
"Per Capita" Fish/Shellfish Consumption (grams/day) and Mercury Exposure (µg/kg bw/day) Based on Average of Three 24-Hour Dietary Recalls — CSFII 89-91

Females Aged 15-45	25th	50th	75th	95th	Maximum Value
Fish/shellfish Consumption	Zero	Zero	15	72	461
Mercury Exposure	Zero	Zero	0.03	0.20	2.76

Table 4-63
"Per User" Fish/Shellfish Consumption (grams/day) and Mercury Exposure (µg/kg bw/day) Based on Average of Three 24-Hour Dietary Recalls — CSFII 89-91

Females Aged 15-45	25th	50th	75th	95th	Maximum Value
Fish/shellfish Consumption	19	31	56	113	461
Mercury Exposure	0.04	0.08	0.16	0.33	2.76

Children consume more food on a body weight basis than do adults. Consequently children have higher exposures to a variety of food contaminants (National Academy of Sciences, 1993) including mercury. Overall, approximately 11 to 13 % of adults report fish/shellfish consumption in short-term consumption estimates based on single 24-hour recall data. For children, the percent who report fish consumption in similar surveys is about 8 to 9%.

Looking at the quantity of fish consumed and the intake of mercury on a body weight basis (i.e., µg Hg/kg body weight/day), the highest environmental dose of mercury from consumption of fish and shellfish is found among children (Tables 4-64 and 4-65) based on fish intake and mercury exposures estimated from single-day estimates. Exposure (on a per kg/bw basis) among children ages 10 and younger are elevated compared with adult values. Children in the age range 11 through 14 years have mercury doses (µg Hg/kg body weight/day) more comparable to adult values than to those of younger children. When the NHANES III data are grouped by age category, exposure patterns shown in Table 4-64 are identified. Higher doses of mercury relative to body weight (µg/kg body weight/day) were also observed in data from CSFII 94 and CSFII 95 (Table 4-66).

Table 4-64
Consumption of Fish and Shellfish (grams/day) and Mercury Exposure (µg Hg/kg bw/day) among Different Age Categories of Children, *Based on Individual Day Data*
(Data from the NHANES III, 1988-1994)

Age Group, Years	Fish Consumption grams/day	Mercury Exposure µg/kg body weight/day
Less than 2 years		
50th Percentile	29	0.33
90th Percentile	95	0.98
95th Percentile	115	1.33
3 through 6 years		
50th Percentile	43	0.28
90th Percentile	113	0.77
95th Percentile	151	1.08
7 through 10 years		
50th Percentile	77	0.31
90th Percentile	178	0.86
95th Percentile	270	1.08
11 through 14 years		
50th Percentile	63	0.15
90th Percentile	158	0.42
95th Percentile	215	0.68

Table 4-65
Fish and Shellfish Consumption (grams/day) and Mercury Exposure (µg/kg body weight/day) for Children Aged 14 years and Younger — CSFII 89-91
Based on Average of Three 24-Hour Recalls

Gender	25th	50th	75th	95th	Maximum Value
"Per User"					
Females	13 0.08	24 0.17	38 0.34	75 0.85	154 1.69
Males	14 0.09	23 0.17	43 0.29	87 0.63	139 1.51
"Per Capita"					
Females	Zero Zero	Zero Zero	7 Zero	43 0.39	155 1.69
Males	Zero Zero	Zero Zero	5 0.01	52 0.33	139 1.51

Table 4-66
"Per User" Fish and/or Shellfish Consumption (grams/day) and Mercury Exposure (µg Hg/kg bw/day) by Children ages 14 and Younger Based on Individual Day Data.

Survey	10th	50th	90th	95th	Maximum
CSFII 94 - Day 1 n=148	15 0.04	53 0.13	127 0.77	176 1.06	293 1.56
CSFII 94 - Day 2 n=162	16 0.07	53 0.20	156 0.67	171 0.91	384 2.70
CSFII 95 - Day 1 n=126	16 0.04	57 0.23	185 0.69	204 0.81	305 5.93
CSFII 95 - Day 2 n=148	13 0.03	53 0.23	170 1.00	243 1.98	305 2.63
NHANES III *1988-1994* *n=1,062*	14 0.04	51 0.25	155 0.83	185 1.08	915 6.95

Comparison of the "per capita" and "per user" values indicate that Asian Americans and Pacific Islanders consume fish and shellfish more frequently than other subpopulations. However, the quantity of fish and shellfish consumed per person is actually smaller than for the other subpopulations Table 4-67). If mercury exposure is expressed on a body weight basis (µg Hg/kg body weight), the exposures are more comparable although Asian Americans/Pacific Islanders have lower exposure to mercury (on a body weight basis) than do other ethnically diverse subpopulations (Table 4-67).

Table 4-67
Consumption of Fish and Shellfish (grams/day) and Mercury Exposure (µg Hg/kg bw/day) Among Ethnically Diverse Groups, *Based on Individual Day Recalls*
(Source: CSFII 94 and CSFII 95)

Ethnic Group	Per Capita[1]		Per User[2]	
	Fish Consumption *grams/day*	**Mercury Exposure** *µg/kg bw/day*	**Fish Consumption** *grams/day*	**Mercury Exposure** *µg/kg bw/day*
White				
50th Percentile	Zero	Zero	72	0.12
90th Percentile	24	0.03	192	0.46
95th Percentile	80	0.14	243	0.67
Black				
50th Percentile	Zero	Zero	82	0.14
90th Percentile	48	0.05	228	0.54
95th Percentile	104	0.19	302	0.96

Table 4-67 (continued)
Consumption of Fish and Shellfish (grams/day) and Mercury Exposure (µg Hg/kg bw/day) Among Ethnically Diverse Groups, *Based on Individual Day Recalls*

Ethnic Group	Per Capita[1]		Per User[2]	
	Fish Consumption *grams/day*	**Mercury Exposure** *µg/kg bw/day*	**Fish Consumption** *grams/day*	**Mercury Exposure** *µg/kg bw/day*
Asian and Pacific Islander				
50th Percentile	Zero	Zero	62	0.10
90th Percentile	80	0.15	189	0.39
95th Percentile	127	0.30	292	0.56
Native American and Alaska Native			*Estimate not made because of small numbers of respondents.*	*Exposures not made because of small numbers of respondents.*
50th Percentile	Zero	Zero		
90th Percentile	Zero	Zero		
95th Percentile	56	0.03		
Other				
50th Percentile	Zero	Zero	83	0.18
90th Percentile	Zero	Zero	294	0.64
95th Percentile	62	0.13	327	0.81

[1]*Total number of 24-hour food consumption recall reports: White (16,241); Black (2,580); Asian and Pacific Islander (532); Native American and Alaska Native (166): and Other (1,195).*
[2] *Number of 24-hour food consumption recall reports: White (1,821); Black (329); Asian and Pacific Islander (155); Native American and Alaska Native (12); and Other (98).*

4.4.3 Month-Long Estimates for Consumers

The third NHANES included survey questions on the frequency of consumption of fish and shellfish that permitted nationally based estimates on how frequently people in the general United States population consume fish and shellfish over a month-long period. The typical frequency of consumption combined with a "snap shot" of typical consumption on *any single day as shown in the "per user" 24-hour recall data* permit projection of moderate-term patterns of fish/shellfish consumption. It is these moderate-term patterns that are the most relevant exposure period for the health-based endpoint that formed the basis of the RfD - i.e., developmental deficits in children following maternal exposure to methylmercury. Additional description of the particular importance of moderate-term patterns of mercury exposure from fish/shellfish intakes is found in Section 4.1.1 (page 4-1 through 4-3 of this Volume).

The frequency of fish and shellfish consumption can be determined from the food frequency data obtained in NHANES III. By combining the number of times per month a person eats fish and shellfish with the 24-hour recall data that provide an estimate of portion size and species of fish/shellfish selected, a projection can be made of the consumption pattern over a month. The statistical methods describing how these two frequency distributions were combined is presented in Appendix D. The month-long projection of fish/shellfish consumption for the general population is shown in Table 4-68a and 4-68b; the estimate for women of childbearing age (assumed to be 15 through 44 years) is shown in Tables 4-69 and 4-70, and the estimates for children are shown in Tables 4-71 and 4-72.

Table 4-68a
Month-Long Estimates of Fish and Shellfish Consumption (gms/day)
General Population by Ethnic/Racial Group
National Estimates Based on NHANES III Data

White/NonHispanic		Black/NonHispanic		Other	
Percentile	Fish/Shellfish gms/day	Percentile	Fish/Shellfish gms/day	Percentile	Fish/Shellfish gms/day
50th	8	50th	10	50th	9
75th	19	75th	25	75th	27
90th	44	90th	58	90th	70
95th	73	95th	97	95th	123
Percentile at which consumption equals approximately 100 grams/day.	97.3th Percentile	Percentile at which consumption equals approximately 100 grams/day.	95.1th Percentile	Percentile at which consumption equals approximately 100 grams/day.	94.6th percentile

Table 4-68b
Month-Long Estimates of Mercury Exposure (µg/kgbw/day)
Population by Ethnic/Racial Group
National Estimates Based on NHANES III Data

White/NonHispanic		**Black/NonHispanic**		**Other**	
Percentile	**Mercury Exposure µg/kgbw/day**	**Percentile**	**Mercury Exposure µg/kgbw/day**	**Percentile**	**Mercury Exposure µg/kgbw/day**
50th	**0.02**	**50th**	**0.02**	**50th**	**0.02**
75th	**0.04**	**75th**	**0.05**	**75th**	**0.06**
90th	**0.09**	**90th**	**0.13**	**90th**	**0.17**
95th	**0.15**	**95th**	**0.21**	**95th**	**0.31**

Table 4-69
Month-Long Estimates of Exposure to Fish and Shellfish (gms/day)
for Women Ages 15 through 44 Years
Combined Distributions Based on NHANES III Data

Percentile	Fish/Shellfish (gms/day)
50th	9
75th	21
90th	46
95th	77
Percentile at which consumption exceeds approximately 100 grams/day based on month-long projections	97th percentile

Table 4-70
Month-Long Estimates of Mercury Exposure (µg/kg*bw*/day) for Women Ages 15 through 44
All Subpopulations Combined
National Estimates Based on NHANES III Data

Percentiles	Mercury Exposure µg/kg*bw*/day Month-Long Estimates
50th	0.01
75th	0.03
90th	0.08
95th	0.13
99th	0.37

Table 4-71
Month-Long Estimates of Fish/Shellfish Consumption (gms/day)
among Children Ages 3 through 6 Years.
National Estimates Based on NHANES III Data

Percentile	Per User Month-Long Estimate	
	Fish/Shellfish Consumption (grams/day)	Mercury Exposure (µg/kg*bw*/day)
50th	**5**	**0.03**
75th	**12**	**0.08**
90th	**25**	**0.18**
95th	**39**	**0.29**

Table 4-72
Month-Long Estimates of Exposure to Fish and Shellfish (gms/day) and
Mercury (µg/kg*bw/day*) among Children Ages 3 through 6 Years
National Estimates for Individual Ethnic/Racial Groups

Percentile		All Groups	White/ NonHispanic	Black/ NonHispanic	Other
50th	**Fish (grams/day)**	5	5	6	7
	Mercury (µg/kg*bw/day*)	0.03	0.03	0.03	0.04
75th	**Fish (grams/day)**	12	11	13	17
	Mercury (µg/kg*bw/day*)	0.08	0.08	0.08	0.11
90th	**Fish (grams/day)**	25	24	28	36
	Mercury (µg/kg*bw/day*)	0.18	0.17	0.19	0.25
95th	**Fish (grams/day)**	39	37	44	57
	Mercury (µg/kg*bw/day*)	0.29	0.28	0.33	0.42

4.4.4 Habitat of Fish Consumed and Mercury Exposure from Fish of Marine, Estuarine and Freshwater Origin

Fish and shellfish species have been grouped into those inhabiting marine, estuarine, and freshwater environments. This classification was developed by US EPA's Office of Water based on advise from fisheries biologists. Categories of fish and shellfish into those primarily inhabiting marine, estuarine, and freshwater environments was shown in Table 4-17.

State and local authorities frequently have obtained data on mercury concentrations in fish in waterways within their boundaries. Thirty-eight states in the United States have issued advisories regarding mercury exposures that will occur through consumption of these fish. Nine states have state-wide advisories that either are based primarily upon or include concern for mercury exposures from these fish. At a local level, the mercury concentrations in fish vary widely. Exposures to methylmercury will vary with the proportion of fish obtained from local sources and from interstate commerce.

Estimates have been made of a national pattern indicating the mixture of marine, estuarine, and freshwater source of fish and shellfish. Tables 4-73 and 4-74 are based on the fish/shellfish consumption data from NHANES III combined with the mercury concentration data of the NMFS and data reported by Bahnick et al. (1988) on mercury concentrations in freshwater fish coming from a nationally based sample of fish and shellfish. Consumption of fish and shellfish from a particular geographic site may result in higher or lower exposures to methylmercury.

Among the three habitat types, overall consumption of freshwater fish and shellfish resulted in the highest mercury exposure per kilogram body weight, followed by marine and estuarine fish and shellfish. Men reported higher mercury exposures from freshwater fish than did women. The higher external doses from freshwater fish are, in part, a reflection of larger serving sizes reported when freshwater species are consumed.

Table 4-73
Exposure of Men Ages 15 to 44 Years to Mercury (µg Hg/kg bw/day)
from Fish and Shellfish of Marine, Estuarine, and Freshwater Origin
Based on Individual Day Recalls
(Food Consumption Data from NHANES III and
Mercury Concentration Data from NMFS and Bahnick et al. (1988))

Statistic	Marine Origin n=386	Estuarine Origin n = 198	Freshwater Origin n=60	Combined Origin, i.e., Total Exposure n = 644
Percentiles **10th**	0	0	0.01	0.01
50th	0.10	0.03	0.33	0.11
90th	0.35	0.30	1.26	0.44
95th	0.60	0.44	1.37	0.60
Maximum Values Reported	4.43	0.71	1.91	4.43

Table 4-74
Exposure of Women Aged 15-44 Years to Mercury (µg Hg/kg bw/day) from Fish and Shellfish of Marine, Estuarine, and Freshwater Origin
Based on Individual Day Recalls
(Food Consumption Data from NHANES III and Mercury Concentration Data from NMFS and Bahnick et al. (1988))

Statistic	Marine Origin n = 581	Estuarine Origin n = 221	Freshwater Origin n = 82	Combined Origin, i.e., Total Exposure n = 882
Percentiles				
10th	0.01	0.01	0.04	0.01
50th	0.10	0.03	0.18	0.10
90th	0.41	0.14	0.50	0.39
95th	0.56	0.23	0.77	0.53
Maximum Reported Value	3.59	0.39	0.91	3.59

4.4.5 Methylmercury Consumption

Quantities of methylmercury consumed in fish depend upon both the quantity of fish consumed and the methylmercury concentration of the fish. Although they are infrequently consumed, swordfish, barracuda and shark have a much higher methylmercury concentration than other marine finfish, freshwater finfish or shellfish. By contrast most shellfish contain low concentrations of methylmercury resulting in far lower methylmercury exposures than would occur if finfish species were chosen.

4.5 Conclusions on Methylmercury Intake from Fish

Methylmercury intakes calculated in this chapter have been developed for a nationally based population rather than site-specific estimates. Food consumption data was provided from the CSFII 89/91, CSFII 94, CSFII 95, and NHANES III surveys. Methylmercury intakes calculated in this chapter have been developed for a nationally based rather than site-specific estimates. The CSFII 89-91 from USDA was designed to represent the U.S. population. The concentrations of methylmercury in marine fish and shellfish were from a data base that is national in scope. Data on freshwater finfish were taken from two large studies that sampled fish at a number of sites throughout the United States. The extent of applicability of these data to site-specific assessments must rest with the professional judgments of the assessor. Because of the magnitude of anthropogenic, ambient mercury contamination, the estimates of methylmercury from fish do not provide a value that reflects methylmercury from nonindustrial sources. "Background" values imply an exposure against which the increments of anthropogenic activity could be added. This is not the situation due to release of substantial quantities into the environment.

Issues dealing with confidence in data on the methylmercury concentration of fish consumed include the following:

- In a number of situations individuals cannot identify with accuracy the species of fish consumed. The USDA Recipe File Data Base has "default" fish species specified if the respondent does not identify the fish species consumed. There is no way, however to estimate the magnitude of uncertainty encountered by misidentification of fish species by the survey respondents.

- The data base used to estimate methylmercury concentrations in marine fish and shellfish was provided by the NMFS. This data base has been gathered over approximately the past 20 years and covers a wide number of species of marine fish and shellfish. The number of fish samples for each species varies but typically exceeds 20 fish per species.

- The analytical quality of the data base has been evaluated by comparison of these data with compliance samples run for the U.S. FDA. The National Academy of Sciences' Report on *Seafood Safety* and the U.S. FDA have found this data base from NMFS to be consistent with 1990s data on methylmercury concentrations in fish.

- The methylmercury concentrations in freshwater fish come from two publications, each giving data that represent freshwater fish from a number of locations. These data were gathered between the early 1980s and early 1990s. These surveys by U.S. EPA (1992), Bahnick et al. (1994), and Lowe et al. (1985) report different mean mercury concentrations; 0.260 µg/g mercury (wet weight) and 0.114 µg/g mercury (wet weight), respectively. The extent to which either of these data sets represents nationally based data on freshwater fish methylmercury concentrations remains uncertain.

- Month-long estimates of mercury exposure from fish and shellfish consumption are considered the exposure projection most relevant to the health endpoint of concern; i.e., developmental deficits among children following maternal fish consumption.

- Because methylmercury is a developmental toxin, a subpopulation of interest is women of child-bearing age. In this analysis of methylmercury intake, dietary intakes of women aged 15 through 44 years were used to approximate the diet of the pregnant woman. From data on Vital and Health Statistics, it has been determined that 9.5% of women of reproductive age can be anticipated to be pregnant within a given year. Generally food intake increases during pregnancy (Naismith, 1980). Information on dietary patterns of pregnant women has been assessed (among other see Bowen, 1992; Greeley et al., 1992). Most of these analyses have focussed on intake of nutrients rather than contaminants. It is uncertain whether or not pregnancy would modify quantities and frequency of fish consumed beyond any increase that may result from increased energy (i.e., caloric) intake that typically accompanies pregnancy.

- Based on available data on fish consumption in the 3 through 6 year age group, it is estimated that 19 to 26% of these children consume relatively more fish on a per kilogram per body-weight basis than do adults, which may result in higher mercury exposure these children. The range reflects differences in mercury exposures between subpopulations categorized on the basis of race and ethnicity. Persons of Asian/Pacific Islander, non-Mexican Hispanics (largely persons of Caribbean ethnicity), Native Americans, and Alaskan Natives have the highest exposures.

- Because mercury concentrations in fish/shellfish are highly variable, information on fish/shellfish consumption (grams/day) are also of interest. It is estimated that 3% of women have month-long fish/shellfish intakes of 100 grams per day and higher based on the NHANES III data.

5. POPULATION EXPOSURES - NON-DIETARY SOURCES

5.1 Dental Amalgams

Dental amalgams have been the most commonly used restorative material in dentistry. A typical amalgam consists of approximately 50% mercury by weight. The mercury in the amalgam is continuously released over time as elemental mercury vapor (Begerow et al., 1994). Research indicates that this pathway contributes to the total mercury body burden, with mercury levels in some body fluids correlating with the amount and surface area of fillings for non-occupationally exposed individuals (Langworth et al., 1991; Olstad et al., 1987; Snapp et al., 1989). For the average individual an intake of 2-20 µg/day of elemental mercury vapor is estimated from this pathway (Begerow et al., 1994). Additionally, during and immediately following removal or installation of dental amalgams supplementary exposures of 1-5 µg/day for several days can be expected (Geurtsen 1990).

Approximately 80% of the elemental mercury vapor released by dental amalgams is expected to be re-absorbed by the lungs (Begerow et al., 1994). In contrast, dietary inorganic mercury absorption via the gastrointestinal tract is known the be about 7%. The contribution to the body burden of inorganic mercury is thus, greater from dental amalgams than from the diet or any other source. The inorganic mercury is excreted in urine, and methylmercury is mainly excreted in feces. Since urinary mercury levels will only result from inorganic mercury intake, which occurs almost exclusively from dietary and dental pathways for members of the general public, it is a reasonable biomonitor of inorganic mercury exposure. Urinary mercury concentrations from individuals with dental amalgams generally range from 1-5 µg/day, while for persons without these fillings it is generally less than 1 µg/day (Zander et al., 1990). It can be inferred that the difference represents mercury that originated in dental amalgams.

Begerow et al., (1994) studied the effects of dental amalgams on inhalation intake of elemental mercury and the resulting body burden of mercury from this pathway. The mercury levels in urine of 17 people aged 28-55 years were monitored before and at varying times after removal of all dental amalgam fillings (number of fillings was between 4-24 per person). Before amalgam removal, urinary mercury concentrations averaged 1.44 µg/g creatinine. In the immediate post-removal phase (up to 6 days), concentrations increased by an average of 30%, peaking at 3 days post-removal. After this phase mercury concentrations in urine decreased continuously and by twelve months had dropped to an average of 0.36 µg/g creatinine. This represents a four-fold decrease from pre-removal steady-state urinary mercury levels.

5.2 Occupational Exposures to Mercury

Industries in which occupational exposure to mercury may occur include chemical and drug synthesis, hospitals, laboratories, dental practices, instrument manufacture, and battery manufacture (National Institute for Occupational Safety and Health, (NIOSH) 1977). Jobs and processes involving mercury exposure include manufacture of measuring instruments (barometers, thermometers, etc.), mercury arc lamps, mercury switches, fluorescent lamps, mercury broilers, mirrors, electric rectifiers, electrolysis cathodes, pulp and paper, zinc carbon and mercury cell batteries, dental amalgams, antifouling paints, explosives, photographs, disinfectants, and fur processing. Occupational mercury exposure can also result from the synthesis and use of metallic mercury, mercury salts, mercury catalysts (in making urethane and epoxy resins), mercury fulminate, Millon's reagent, chlorine and caustic soda, pharmaceuticals, and antimicrobial agents (Occupational Safety and Health Administration (OSHA) 1989).

OSHA (1975) estimated that approximately 150,000 US workers are exposed to mercury in at least 56 occupations (OSHA 1975). More recently, Campbell et al., (1992) reported that about 70,000 workers are annually exposed to mercury. Inorganic mercury accounts for nearly all occupational exposures, with airborne elemental mercury vapor the main pathway of concern in most industries, in particular those with the greatest number of mercury exposures. Occupational exposure to methylmercury appears to be insignificant. Table 3-10 summarizes workplace standards for airborne mercury (vapor + particulate).

A number of studies have been reported that monitored workers' exposure to mercury (Gonzalez-Fernandez et al., 1984; Ehrenberg et al., 1991; Cardenas et al., 1993; Kishi et al., 1993, 1994; Yang et al., 1994). Some studies have reported employees working in areas which contain extremely high air mercury concentrations: 0.2 to over 1.0 mg/m^3 of mercury. Such workplaces include lamp sock manufacturers in Taiwan (Yang et al., 1994), mercury mines in Japan (Kishi et al., 1993,1994), a small thermometer and scientific glass manufacturer in the US (Ehrenberg et al., 1991), and a factory producing mercury glass bubble relays (Gonzalez-Fernandez et al., 1984). High mercury levels have been reported in blood and urine samples collected from these employees (reportedly over 100 µg/L in blood and over 200 - 300 µg/L or 100 - 150 µg/g creatinine for urine). At exposures near or over 1.0 mg/m3, workers show clear signs of toxic mercury exposure (fatigue, memory impairment, irritability, tremors, and mental deterioration). The chronic problems include neurobehavioral deficits that persist long after blood and urine mercury levels have returned to normal; many workers required hospitalization and/or drug treatments. With the exception of mercury mines, workplaces producing these mercury levels are typically small and specialized, often employing only a few workers who were exposed to high mercury concentrations.

Many other studies have monitored employees' work areas and reported measured mercury air concentrations of 0.02 - 0.2 mg/m^3; these levels are generally in excess of present occupational standards (see Table 5-1). These mercury levels were most often reported at chlor-alkali plants (Ellingsen et al., 1993; Dangwal 1993; Barregard et al., 1992; Barregard et al., 1991; Cardenas et al., 1993). Employees at these facilities had elevated bodily mercury levels of approximately 10-100 µg/L for urine and about 30 µg/L in blood. At these lower levels, chronic problems persisting after retirement included visual response and peripheral sensory nerve effects.

Exposures to mercury levels under 0.02 mg/m^3 typically result in blood and urine levels statistically higher than the general population, but health effects are usually not observed.

Table 5-1
Occupational Standards for Airborne Mercury Exposure

Concentration Standard (mg/m^3)	Standard Type	Mercury Species	Reference
0.10	STEL	inorganic	CFR (1989)
0.01	TWA	organic	CFR (1989)
0.03	STEL	alkyl	CFR (1989)
0.05	TWA	all besides alkyl	ACGIH (1986)

Table 5-1 (continued)
Occupational Standards for Airborne Mercury Exposure

Concentration Standard (mg/m^3)	Standard Type	Mercury Species	Reference
0.01	TWA	alkyl	ACGIH (1986)
0.03	STEL	alkyl	ACGIH (1986)
0.10	TWA	aryl and inorganic	ACGIH (1986)
0.05	TWA	all besides alkyl	NIOSH (1977)

Abbreviations:
ACGIH - American Conference of Governmental Industrial Hygienists
CFR - Code of Federal Regulations
STEL - Short term exposure limit (15 minutes)
TWA - Time weighted average (8 hour workday)

5.3 Miscellaneous Sources of Mercury Exposure

Inorganic mercury is used in some ritualistic practices (Wendroff, 1995). The extent of this use in the United States is undocumented, although it is considered to be more commonly encountered in Hispanic and Latino communities. Inorganic mercury is distributed around the household in a variety of ways and may result in dermal contact or it potentially be inhaled.

5.4 Cases of Mercury Poisoning

Numerous examples may be found in the literature of unintentional mercury poisoning. The following examples were taken from *Morbidity and Mortality Weekly Report*, a publication of the U.S. Public Health Service, Centers for Disease Control. These cases studies indicate that mercury has diverse — although, in many cases, illegal — applications. The studies illustrate the wide range of potential health effects from mercury exposure including death.

Unsafe Levels of Mercury Found in Beauty Cream

Between September 1995 and May 1996, the Texas Department of Health, the New Mexico Department of Health, and the San Diego County Health Department investigated three cases of mercury poisoning associated with the use of a mercury-containing beauty cream produced in Mexico. The cream, marketed as “Crema de Belleza-Manning” for skin cleansing and prevention of acne, has been produced since 1971. The product listed “calomel” (mercurous chloride) as an ingredient and contained 6% to 10% mercury by weight. Because mercury compounds are readily absorbed through the skin, FDA regulations restrict the use of these compounds as cosmetic ingredients. Specifically, mercury compounds can be used only as preservatives in eye-area cosmetics at concentrations not exceeding 65 ppm of mercury; no effective and safe nonmercurial substitute preservative is available for use in such cosmetics.

An ongoing investigation of the cream located it in shops and flea markets in the United States near the U.S.-Mexico border, and identified a U.S. organization in Los Angeles as the distributor. Media announcements, warning of the mercury containing cream, were then made in Arizona, California, New Mexico, and Texas. In response to these announcements, 238 people contacted their local health departments to report using the cream. Urinalysis was conducted for 119 people, and of these, 104 had elevated mercury levels. Elevated urine mercury levels were also detected in people who did not use the cream but who were close household contacts of cream users.

Indoor Latex Paint Found to Contain Unsafe Mercury Levels

In August 1989, a previously healthy 4-year-old boy in Michigan was diagnosed with acrodynia, a rare manifestation of childhood mercury poisoning. A urine mercury level of 65 µg/L was measured in a urine sample collected over 24 hours. Examinations of his parents and two siblings also revealed elevated urine mercury levels. The Michigan Department of Public Health (MDPH) determined that inhalation of mercury-containing vapors from phenylmercuric acetate contained in latex paint was the probable route of mercury exposure for the family; 17 gallons of the paint had been applied to the inside of the family's home during the first week of July. During that month, the air conditioning was turned on and the windows were closed, so that mercury vapors from the paint were not properly vented. In addition, samples of the paint contained 930-955 mg/L mercury, while the EPA limit for mercury as a preservative in interior paint is 300 mg/L.

In October, the Michigan Department of Agriculture prohibited further sales of the inappropriately formulated paint, and the MDPH advised people not to use the paint, to thoroughly ventilate freshly painted areas, and to consult a physician if unexplained health problems occurred. In November, the MDPH and Centers for Disease Control began an ongoing investigation in selected communities in southeastern Michigan to assess mercury levels in the air of homes in which this paint had been applied and in urine samples from the occupants.

Jar of Mercury Spilled in Ohio Apartment

In November 1989, a 15-year-old male from Columbus, Ohio was diagnosed with acrodynia, a form of mercury poisoning. A 24-hour urine collection detected a mercury level of 840 µg/L in the patient's urine. The patient's sister and both his parents were also found to have elevated mercury urine levels. Therefore, on November 29, the Columbus Health Department investigated the apartment where the family had lived since August 26, 1989. Neighbors reported that the previous tenant had spilled a large jar of elemental mercury within the apartment. Mercury vapor concentrations in seven rooms ranged from 50-400 µg/m^3. The Agency for Toxic Substances and Disease Registry's acceptable residential indoor air mercury concentration is less than or equal to 0.5 µg/m^3.

Mercury Vapors Released in House During Smelting Operation

On August 7, 1989, four adults from Michigan, ranging from age 40 to 88, were hospitalized for acute mercury poisoning. All four patients lived in the same house, where one of the patients had been smelting dental amalgam in a casting furnace in the basement of the house in an attempt to recover silver. Mercury fumes were released during the smelting operation, entered air ducts in the basement, and were circulated throughout the house. All four patients died of mercury poisoning within 11-24 days after exposure.

Mercury Spilled in Michigan House

During the summer of 1989, a boy in Michigan spilled about 20 cm^3 of liquid mercury in his bedroom. In September of that year, both of his sisters were diagnosed with mercury poisoning, after exhibiting clinical symptoms associated with such poisoning. The boy, although asymptomatic, was also tested and was found to have elevated mercury levels.

Florida School Children Find Elemental Mercury in Abandoned Van

During August 1994, five children residing in a neighborhood in Palm Beach County, Florida found 5 pints of elemental mercury in an abandoned van. During the ensuing 25 days, the children shared and played with the mercury outdoors, inside homes, and at local schools. On August 25, 1994, a parent notified local police and fire authorities that her children had brought mercury into the home. That same day, 50 homes were immediately vacated and an assessment of environmental and health impacts was initiated by the State of Florida Department of Environmental Protection, the Health and Rehabilitation Services of the Palm Beach County Public Health Unit, and the U.S. Environmental Protection Agency.

A total of 58 residential structures were monitored for indoor mercury vapor concentrations; unsafe indoor air levels of mercury ($>15\ \mu g/m^3$) were detected in 17. Several classrooms at the local high schools were determined to be contaminated. In addition, 477 people were identified by the survey as possibly exposed to mercury vapors and were evaluated at the emergency department of the local hospital or the health department clinic for mercury poisoning. Of these people, 54 were found to have elevated mercury levels.

Unsafe Mercury Levels Found in North Carolina Home

In July 1988, the Environmental Epidemiology Section of the North Carolina Department of Environment, Health, and Natural Resources (DEHNR), investigated chronic mercury poisoning diagnosed in a 3-year-old boy from North Carolina. Results of 24-hour urine specimens for mercury collected from both the patient and his parents revealed elevated mercury levels. Although the family reported no known mercury exposures, in April 1988, they had moved into a house whose previous owner had collected elemental mercury. Several containers of mercury had reportedly been spilled in the house during the previous owner's occupancy. As a result of the determination that the house was the probable source of exposure, the family temporarily relocated.

The DEHNR conducted an extensive investigation of the house. Elevated mercury levels were detected in five rooms and two bathrooms. The vacuum cleaner filter bag was tested for mercury as well, and found to have extremely high mercury levels. The carpets were also heavily contaminated with mercury. When the contaminated carpets were vacuumed, mercury particles and vapor were probably dispersed throughout the house. Vaporization probably increased with the spread of the mercury and the onset of warmer weather.

6. COMPARISON OF ESTIMATED EXPOSURE WITH BIOMONITORING

6.1 Biomarkers of Exposure

Biologic markers, as described by the U.S. National Research Council (NRC, 1989) are indicators signaling events in biological systems or samples. These are classified as biologic markers of exposure, effect and susceptibility. A biological marker of exposure is defined by the National Research Council (1989) an "exogenous substance or its metabolite(s) or the product of an interaction between a zenobiotic agent and some target molecule or cell that is measured in a compartment within an organism" (NRC, 1989, pg. 2). Concentrations of mercury and of methylmercury in biological materials are used as biomarkers of exposure to mercury in the environment.

Mercury accumulates in body organs. Although concentrations of mercury in organs adversely affected by mercury (e.g., neural tissue, the kidney) may be more predictive of levels of exposure at the site of organ system damage, for purposes of monitoring exposures mercury concentrations in tissues less proximal are relied upon. Typically mercury concentrations in blood, hair, and urine are used to assess exposure to organic and inorganic mercury.

6.2 Biomarkers of Exposure Predictive of Intake of Methylmercury

Humans are exposed to both organic (e.g., methylmercury) and inorganic mercury. The proportion of organic to inorganic mercury exposure depends on exposure conditions. Organic methylmercury almost exclusively occurs through consumption of fish and shellfish. Occupational exposure to organic mercury compounds is far less common than are occupational exposures to inorganic mercury compounds. Within occupations where exposures to organic mercury compounds occur, great caution must be taken to assure that people handling such compounds do not come into contact with organic mercury because of its extreme toxicity. Inorganic mercury exposures reflect sources including dental amalgams and occupational sources with minor contributions from certain hobbies and ritualistic uses of mercury. Contribution from "minor" sources refers to their overall use in the general population. Such "minor" sources can produce highly elevated exposures and poisoning of individuals who use these products.

Blood and hair concentrations of mercury can be used to back calculate estimates of methylmercury ingested. Because methylmercury in the diet comes almost exclusively from consumption of fish and shellfish, methylmercury concentrations in blood and hair are very strong predictors of methylmercury ingestion from fish and shellfish.

The fraction of methylmercury absorbed via the gastrointestinal tract from fish and shellfish is extremely high; typically more than 95% (REFS). After absorption methylmercury is transported in the blood. There is a strong affinity for the erythrocyte (Aberg et al., 1969; Miettinen, 1971). Standard reference values for blood mercury concentrations indicate packed cells are 10-times more concentrated in mercury than is whole blood (Cornelis et al., 1996). Methylmercury is distributed throughout the body including distribution into the central nervous system. Postabsorption and distribution to tissues, methylmercury is slowly demethylated and converted to inorganic mercury (Burbacker and Mottet, 1996).

A portion of the inorganic mercury arising from demethylation of methylmercury is present in blood (Smith and Farris, 1996). Additional sources of inorganic mercury include dental amalgams in persons with silver-mercury dental restorations, small amounts of inorganic mercury absorbed from diet, and for some individuals occupational and/or miscellaneous sources. Although inorganic mercury is present in blood, under most conditions the predominant chemical species of mercury in blood is methylmercury arising from consumption of fish and shellfish.

6.3 Sample Handling and Analysis of Blood Samples for Mercury

The predominant method of chemical analysis of total mercury in blood is based on cold vapor absorbance techniques (IUPAC, 1996; Nixon et al., 1996). Atomic fluorescence is also a very sensitive and reliable technique for mercury measurement in blood, serum and urine (IUPAC, 1996). The various mercury-species are converted by reducing agents to elemental mercury and released as a vapor which is either directly pumped through the cell of the atomic absorption spectrophotometer or analyzed after amalgamation and enrichment on gold (IUPAC, 1996).

Sample pretreatment to destroy the organic matter in samples and avoid losses of mercury through volatilization are key considerations in the analytic procedure for determination of inorganic and total mercury. Digestion procedures have been developed that permit conversion of organic mercury compounds and arylmercury to inorganic mercury, but do not convert significant quantities of alkylmercury (i.e., methylmercury) to inorganic mercury (Nixon et al., 1996).

The expected concentration cited by IUPAC (1996) for mercury in serum of healthy individuals is 0.5 µg/L. In packed cells the level is about 5 µg/kg. Standard reference materials for mercury in whole blood are available in the range of 4 to 14 µg/L. Using the IUPAC (1996) expected concentration, whole blood mercury would be less than 2.5 µg/L.

Sample handling prior to analysis is always critical in obtaining optimal analytical results. The Commission of Toxicology of the IUPAC has described an organized system for collection and handling of human blood and urine for the analysis of trace elements including mercury (1996).

6.4 Association of Blood Mercury with Fish Consumption

6.4.1 Half-Lives of Methylmercury in Blood

The half-life of mercury in blood varies with prior intake of methylmercury and individual characteristics. Previous investigations with methylmercury ingestion under controlled conditions provide estimates of half-lives among adults. Data on half-lives among children do not appear to exist. Two studies among adults are particularly informative. Sherlock et al. (1984) evaluated half-lives for methylmercury ingested via halibut by 14 adult male and 7 adult female volunteers over a period of 96 days. Overall, the half-life for mercury in blood was calculated by Sherlock et al. as 50±1 days (mean±standard error; range 42 to 70 days) for adult subjects. Another approach is that used by Birke et al. (1972) based on repeated blood sampling of subjects after termination of chronic ingestion at higher levels of methylmercury consumption. Data from the study of Birke et al. (1972) showed two subjects with half-lives of 99 and 120 days in blood cells and 47 and 130 days in plasma. Additional data on half-lives of methylmercury ingested via fish were reported by Miettinen et al. (1971) following single ingestion of radiolabelled fish. Miettinen et al. (1971) using ^{203}Hg-labelled methylmercury incorporated into burbot (*Lota vulgaris*) fed as a single dose to 15 adult volunteers determined a mean biological half-time of 50±7 days (mean±standard deviation of the mean) in red blood cells for five male subjects and one female subject.

Overall the metabolic data support the use of blood mercury as an indicator of recent methylmercury intake. The range surround mean half-lives reflect the combined influence of individual person-to-person characteristics, previous intake of methylmercury, and level of methylmercury ingestion. During the 1990s, a number of additional reports on total blood mercury and on organic methylmercury in blood have confirmed that higher intakes of fish/shellfish are associated with increasing concentrations of total mercury, and in particular a higher fraction of methylmercury (Mahaffey and Mergler, in press).

6.4.2 Fraction of Total Blood Mercury that Is Organic or Methylmercury

Among subjects with blood total mercury levels less than 5 µg/L, Oskarsson et al. (1996) reporting on 30 women living in northern Sweden found that 26% of blood mercury was organic mercury. By contrast women who consumed large amounts of seafood had 80% organic mercury at delivery in maternal blood from Inuit women in Greenland (Hansen et al., 1990), and approximately 83% organic mercury in Faroese women (Grandjean et al., 1992). High blood levels of total mercury were reported by Akagi et al. (1995) among residents of the Amazon. In fishing villages where blood total mercury levels were approximately 100 µg/L, 98% of total mercury was organic (methyl) mercury. Aks et al. (1995) in another study of adult Amazon villagers, found approximately 90% of total mercury to be organic mercury when blood levels were approximately 25 to 30 µg/L. Mahaffey and Mergler (in press) found that there was a linear increase (when the data were log transformed) in the fraction of total blood mercury that was present as organic mercury over a blood total mercury up to 70 µg/L.

6.4.3 Methylmercury Consumption from Fish and Blood Mercury Values

Increasing frequency of fish consumption is predictive of higher total blood mercury concentrations; particularly increased concentrations of organic mercury (i.e., methylmercury) in blood (Brune et al., 1991; Hansen et al., 1990; Svensson et al., 1992; Weihe et al., 1996). Within the non-occupationally mercury exposed population, frequency, quantity and species of fish consumed produce differences in methylmercury ingestion and in blood mercury concentrations. Brune et al. (1991) reviewed the literature on total mercury concentrations in whole blood and associated these with the number of fish meals/week (Table 6-1). Although there is a clear increase in mean values with increasing frequency of fish consumption, the ranges of values (e.g., 10th and 90th percentiles) overlap with the next highest category of consumption. These ranges illustrate some of the difficulty of characterizing methylmercury intake simply by the reports describing number of fish meals consumed per week.

Table 6-1
Literature Derived Values for Total Mercury Concentrations in Whole Blood
(from Brune et al., 1990)

Level of Fish Consumption	Mean Value	10th and 90th Percentiles	25th and 75th Percentiles	Number of Observations
Category I, No Fish Consumption	20	0, 4.3	0.8, 3.2	223
Category II, < 2 Fish Meals/Week	4.8	2.4, 7.2	3.5, 6.1	339
Category III, ≥ 2-4 Fish Meals/ Week	8.4	2.6, 14.2	5.4, 11.4	658

Table 6-1 (continued)
Literature Derived Values for Total Mercury Concentrations in Whole Blood
(from Brune et al., 1990)

Level of Fish Consumption	Mean Value	10th and 90th Percentiles	25th and 75th Percentiles	Number of Observations
Category IV, > 4 Fish Meals/Week	44.4	6.1, 82.7	24.4, 64.4	613
Category V, Unknown Fish Consumption	5.8	1.2, 10.4	3.4, 8.2	3182

The analysis by Brune et al. (1990) demonstrated the limitations of determining a methylmercury intake based on the number of fish meals/week. Nonetheless there is an association between frequency of fish meals and blood mercury levels. If the exposure analysis is further refined to include a description of the size of the serving of fish consumed, and information on the mercury content of the fish, the association with blood mercury concentration is strengthened.

6.4.4 North American Reports on Blood Mercury Concentrations

6.4.2.1 United States

Normative data to predict blood mercury concentrations for the United States population are not available. With a very few exceptions all of the data that have been identified are for adult subjects. The largest single study appears to be that of former United States Air Force pilots. Kingman et al. (Kingman et al., in press; Nixon et al., 1996) analyzed urine and blood levels among 1127 Vietnam-era United States Air Force pilots (all men, average age 53 years at the time of blood collection) for whom extensive dental records were available. Blood values were determined for total mercury, inorganic mercury and organic/methylmercury. Mean total blood mercury concentration was 3.1 µg/L with a range of "zero" (i.e., detection limit of 0.2) to 44 µg/L. Overall, 75% of total blood mercury was present as organic/methylmercury. Less than 1% of the variability in total blood mercury was attributable to variation in the number and size of silver-mercury amalgam dental restorations. Dietary data on the former pilots were very limited, so typical patterns of fish consumption are not reported.

Additional North American studies have been reported by various individual states in the United States. These are described below and summarized in Table 6-2.

Arkansas

The Arkansas Department of Health reported on total blood mercury for 236 individuals with a mean of 10.5 µg/L (range "zero" to 75 µg/L) (Burge and Evans, 1996). Of these, 139 participants had total blood mercury above 5 µg/L and 36 participants had blood mercury concentrations more than 20 µg/L. To have been included in the survey, subjects had to confirm that their fish consumption rate was a minimum of two meals per month with eight ounces of fish per meal.

Table 6-2
Blood Mercury Concentrations Values Reported for the United States

Study	Community	Measure of Central Tendency	Maximum	Additional Information on Study
Burge and Evans (1996)	236 participants from Arkansas	Mean: 10.5 µg/L; among men: 12.8 µg/L; among women, 6.9 µg/L. Median: All subjects 7.1 µg/L Men: 9.0 µg/L Women: 4.8 µg/L	All subjects: 75 µg/L Males: 75 µg/L Females: 27 µg/L.	139 participants exceeded 5 µg/L. 30 participants in the range of 20 to 75 µg/L or 15% >20 µg/L. 5% of men had >30 µg/L. No women had values > 30 µg/L.
Centers for Disease Control (1993)	Micousukee Indian Tribe of South Florida. 50 blood samples from subjects with mean age=34 years (Range 8 to 86 years).	Mean: 2.5 µg/L Median: 1.6 µg/L	13.8 µg/L	
Gerstenberger et al. (1997)	68 Ojibwa Tribal members from the Great Lakes Region	57 participants < 16 µg/L. Remaining 11 subjects averaged 37 µg/L.	53 µg/L	11 individuals had blood mercury in the range 20 to 53 µg/L.
Harnly et al. (1997)	Native Americans living near Clear Lake, California. Group studied include 44 Tribal members, and 4 nontribal members.	Mean for 44 Tribal members: 18.5 µg/L (2.9 µg/L inorganic Hg + 15.6 µg/L for organic Hg). Mean for 4 nontribal members: 11.5 µg/L (2.7 µg/L inorganic + 8.8 µg/L organic Hg).	Among Tribal members: Total Hg was 43.5 µg/L (4.7 µg/L inorganic + 38.8 µg/L organic). For nontribal members: Total Hg 15.6 µg/L (3.4 µg/L inorganic + 12.2 µg/L organic).	20% of all participants (9 persons including four women of childbearing age) had blood mercury concentrations ≥ 20 µg/L.

Table 6-2 (continued)
Blood Mercury Concentrations Values Reported for the United States

Study	Community	Measure of Central Tendency	Maximum	Additional Information on Study
Humphrey and Budd (1996)	Lake Michigan residents studied in 1971.	Algonac, Lake St. Clair: Fisheaters (n=42) mean 36.4 compared with 65 low fish consumers having mean of 5.7 µg/L. South Haven, Lake Michigan with lower Hg contamination. Fisheaters (n=54) had mean 11.8 µg/L and the comparison group of low fish consumers mean (n=42) of 5.2 µg/L	Algonac, Lake St. Clair Fisheaters: 3.0-95.6 µg/L Comparison: 1.1 - 20.6 µg/L South Haven, Lake Michigan Fisheaters: 3.7-44.6 µg/L Comparison: 1.6-11.5 µg/L	Mercury contamination less intense in South Haven compared with Algonac.
Knobeloch et al. (1995)	Family consuming commercially obtained seafood.	Initial blood values for wife (37 µg/L) and husband (58 µg/L) following regular consumption of imported seabass having mercury concentrations estimated at 0.5 to 0.7 ppm Hg.	Six months after family stopped consuming seabass, blood mercury concentrations for the wife (3 µg/L) and husband (5 µg/L) had returned to "background" concentrations.	
Schantz et al. (1996)	Adult men and women aged 50 to 90 years. Michigan residents.	104 fisheaters: mean=2.3 µg Hg/L 84 nonfisheaters: mean=1.1 µg Hg/L.	Maximum for fisheaters: 20.5 µg Hg/L Maximum for nonfisheaters: 5.0 µg Hg/L.	Questionnaire on fish-eating patterns included sport-caught Great Lakes fish and purchased fish, as well as questions on patterns of wild game consumption.

Great Lakes Region

Schantz et al. (1996) reported on blood mercury levels in an older-adult population (ages 50 to 90 years). Blood mercury levels for non-fisheaters averaged 1.1 µg/L and for fish-eaters the average was 2.3 µg/L.

Gerstenberger et al. (1997) determined blood mercury levels for 57 Ojibwas Tribal Members from the Great Lakes Region. Among the 68 participants 57 had blood mercury concentrations < 16 µg/L. The remaining 11 subjects had average blood mercury concentrations of 37 µg/L with a maximum value of 53 µg/L.

Wisconsin

Blood mercury levels among 175 Wisconsin Chippewas Indians who consumed fish from northern Wisconsin lakes that have fish with high mercury concentrations (>1 ppm) were determined (Peterson et al., 1994). Values ranged from nondetectable (i.e., < 1 µg/L) to a high of 33 µg/L. Twenty percent (64 individuals) had blood mercury levels > 5 µg/L. Recent consumption of the fish, walleye, was associated with elevated blood mercury concentrations.

Knobeloch et al. (1995) investigated mercury exposure in a husband and wife and their two-year-old son living in Wisconsin. The individuals had total blood mercury ranging from 37 to 58 µg/L. The family's diet included three to four fish meals per week. The fish was purchased commercially from a local market. Seabass were found to contain mercury at 0.5 to 0.7 ppm. Six months after the family stopped consuming the seabass, blood mercury levels in this man and women declined dramatically to 5 and 3 µg/L, respectively.

California

Harnly et al. (1997) determined blood mercury concentrations for 44 members of Native American tribes and 4 nontribal members living near Clear Lake, California. The mean for the 44 tribal members was 18.5 µg/L total mercury (15.6 µg/L organic and 2.9 µg/L inorganic). The maximum value was 43.5 µg/L (38.8 µg/L organic and 4.7 µg/L inorganic). Twenty percent of all participants (including four women of childbearing age) had blood mercury concentrations $\geq$ 20 µg/L. Among nontribal members total mercury concentrations were lower with a total mercury value of 11.5 (8.8 organic + 2.7 inorganic) µg/L. The highest value for nontribal members was 15.6 (12.2 organic and 3.4 inorganic) µg/L.

Florida

The U.S. Centers for Disease Control (CDC, 1993) conducted a community survey of the tribal representatives of the Miccousukee Indian Tribe living in South Florida. Blood mercury levels were determined for 100 participants who were adult tribal members. Fish consumption among this group was low with a maximum of approximately 170 grams/day and 3.5 grams calculated as a daily average. Total blood mercury ranged from 0.2 to 13.8 µg/L with median and mean values of 1.6 and 2.5 µg/L, respectively. There was a correlation between blood mercury levels and consumption of locally caught fish.

Maine

An additional source of data on blood mercury levels is the heavy metal profiles (for lead, arsenic, cadmium, and mercury) conducted as part of occupational surveillance. Typically the persons who receive this type of screening are expected to have exposures to at least one of these metals. Occupational surveillance may be based on state requirements or Federal statutes. For example, the State of Maine has an occupational disease reporting requirement on individuals whose blood mercury concentrations for total mercury are 5 µg/L and higher and whose urinary total mercury is greater than or equal to 20 µg/L. The State of Maine evaluated data on occupational screening for heavy metal exposure and identified a group of adults having total blood mercury concentrations more than 5 ppb. Several cases of elevated blood mercury concentrations were identified. One case has been reported by Dr. Allison Hawkes (personal communication, 1997). The individual was identified with a blood mercury of 21.4 µg/L. The subject had no known occupational exposure to mercury, but self-reported eating 3 or 4 fish meals per week. The individual was asked to abstain from consuming fish for 4 or 5 weeks and then return for follow-up blood testing. On retesting blood total mercury was only 5 µg/L.

6.4.2.1 Canadian

As in the United States, normative data for the general population of Canada have not been identified in compiling information for this Report to Congress. By contrast to the United States, information on mercury exposures in the northern regions of the country has been obtained. The Department of Indian and Northern Affairs of the Government of Canada reported on Arctic contaminants in the *Canadian Arctic Contaminants Assessment Report* in 1997. Methylmercury levels in blood since 1970. For all Aboriginal Peoples the mean blood mercury concentration was 14.13 (standard deviation 22.63) and a range of 1 to 660 µg/L (Wheatley and Paradis, 1995) based on 38,571 data points from 514 native communities across Canada.

Overall, blood mercury concentrations are considered closely tied to consumption of fish and marine mammals. The highest levels are found among Aboriginal residents with particular high levels found in northern Quebec and among the northern and eastern Inuit communities. No downward trend was evident in Inuit blood mercury concentrations between 1975 and 1987, but more recent data (1992 to 1995) indicated lower levels of mercury in some groups (Jensen et al., 1997, page 336).

Quebec

Within the values reported in the *Canadian Arctic Contaminants Assessment Report* (Jensen et al., 1997) particularly high mean concentrations were observed among the Inuit (Nunavik) of Quebec. Mean total mercury concentration of 47 µg/L (SD 33, range 3 to 267 µg/L) was identified among 1114 Inuit of Quebec. The Northern (Cree) had mean values of 34 (SD 41, range 2 to 649 µg/L) among 4,670 blood values and 42.9 (SD 52, range 2 to 649) based on 1,129 blood values.

North West Territory

The Nunavut (Inuit) of the North West Territory also have elevated blood mercury levels with mean values during the 1970s through late 1980s averaging between 17 and 40 µg/L (upper extent of this range going to 226 µg/L). The Western (Dene) population had lower blood mercury levels with means between 11 and 17 µg/L (upper extent of the Dene range to 138 µg/L).

6.5 Hair Mercury as a Biomarker of Methylmercury Exposure

6.5.1 <u>Hair Composition</u>

Hair is approximately 95% proteinaceous and 5% a mixture of lipids, glycoproteins, remnants of nucleic acids, and in the case of pigmented hairs, of melanin and phaeomelanin. Hair contains a central core of closely packed spindle-shaped cortical cells, each filled with macrofibrils which in turn consist of a microfibril/matrix composite. The long axes of the cells and their fibrous constituents are oriented along the long axis of the hair. The amino acid composition of hair is high in those amino acids with side-chains (particularly, those containing “reactive” groups such as cystine, cysteine, tyrosine, tryptophan, acidic and basic amino acids, as well as terminal carboxyl or amino groups). The cortical core is covered by sheet-like cells of the cuticle. The surfaces of all the cells of the hair shaft have a thin layer of lipid which is covalently attached to the underlying proteins.

Hair has been assumed to grow at the rate of one centimeter a month (Kjellstrom et al., 1989; Marsh et al., 1980). However, there is variability in the rate of hair growth. Growth determined experimentally is between 0.9 and 1.3 cm per month (Barman et al., 1963; Munro, 1966; and Saitoh, 1967).

Mercury is incorporated into hair during the growth of hair. Hair mercury concentrations are presumed to reflect blood mercury concentrations at the moment of hair growth. Whether the predominant chemical species is inorganic mercury or methylmercury depends on exposure patterns and on the extent of demethylation of methylmercury. Hair mercury (ug/g) and blood mercury (ng/L) ratios range from 190:1 up to 370:1 (Skerfving, 1974; Phelps et al., 1980; Turner et al., 1980; Sherlock et al., 1984). Higher ratios have recently been reported. Additional discussion of the hair to blood mercury ratio is found in the volume on human health. This is one source of person-to-person variability considered in selection of uncertainty factors in determining U.S. EPA’s Reference Dose for methylmercury.

Chemical analyses to determine mercury concentrations in hair determine total mercury rather than chemical species of mercury. In order to dissolve hair samples, they must be put through an acid digestion. The process of acid digestion will convert virtually all of the mercury in the biological sample to inorganic mercury (Nixon et al., 1996). Consequently the fraction of hair mercury that is methylmercury is only an estimate based on what is known of environmental/occupational exposure patterns.

The frequency of fish consumption has been used as a guide to differences in hair mercury concentrations (Airey, 1983). Within a general population as fish consumption increases, hair mercury concentration will also increase. However, the amount of mercury in hair depends on the concentration of mercury present in fish consumed. Comparison of recent studies from Bangladesh (Holsbeek et al., 1996) and Papua New Guinea (Abe et al., 1995) illustrates these differences. Holsbeek et al. (1996) found a highly significant positive correlation ($r=0.88$, $P<0.001$) between fish consumption and hair mercury concentrations. Total hair mercury concentrations had a mean value of 0.44 ± 0.19 µg/g (range 0.02 to 0.95) and a fish consumption of 2.1 kg/month (range 1.4 to 2.6). The low concentrations in hair reflect the low concentrations of methylmercury in Bangladesh fish. Abe et al. (1995) evaluated 134 fish-consuming subjects and 13 nonfish-eating subjects in Papua, New Guinea. Among the fish consumers hair mercury levels had a mean mercury concentrations of 21.9 µg/g (range 3.7 to 71.9). Average fish consumption was 280 grams/day (range=52 to 425) or about 8.4 kg/month producing an average methylmercury intake of 84 µg/day. Among the nonfish consumers the mean hair mercury was 0.75 ± 0.4 µg/g. The difference in hair mercury concentration in Bangladesh and New Guinea were considerably greater than the differences in fish mercury.

6.5.2 Hair Mercury Concentrations in North America

6.5.2.1 United States

Data do not exist describing hair mercury concentrations that are representative of the United States population as a whole. This is similar to the situation for blood mercury concentrations. Limited data from smaller studies are described below and summarized in Table 6-3.

U.S. Communities

Crispin-Smith et al. (1997) analyzed hair mercury concentrations in 1431 individuals living in the United States. The communities in which these individuals resided were not identified. Mean values in these studies were < 1 µg/g. Fish consumers had slightly higher blood mercury concentrations than did nonfish consumers (0.52 vs. 0.48). The maximal value reported in this survey was 6.3 µg/g. Statistical information on these data is not available currently.

New York Metropolitan Area, New Jersey, Alabama (Birmingham), and North Carolina (Charlotte)

Creason et al. (1978a, 1978b, and 1978c) evaluated children and adults living in these cities in the early 1970s. Mean values for all groups of children and adults were less than 1 µg/g. Maximum values were in the range of 5 to 11.3 µg/g of hair. Adult values were slightly higher than those of children.

California

Airey (1983) determined hair mercury concentrations among about 100 subjects living in Southern California (LaJolla and San Diego). Mean values were in the range of 2 to 3 µg Hg/gram, with maximum values in the range of 4.5 to 6.6 µg/g.. Harnly et al. (1997) determined hair mercury among Tribal and nontribal group members living near Clear Lake, California. Mean values were typically less than 1 µg/g., with maximum values of 1.8 µg/g. among Tribal members and 2.3 µg/g among non-Tribal members.

Maryland

Airey (1983) found mean concentrations of about 1.5 to 2.3 µg/g in adults living in Maryland (communities were not identified). Maximum concentrations were 4.5 µg/g..

State of Washington

Lazaret et al. (1991) identified hair mercury concentrations < 1 µg/g. and a maximum value of 1.5 µg/g. Earlier Airey (1983) reported mean values of 1.5 to 3.8 µg/g among small numbers of subjects. The maximum value reported was 7. 9 µg/g.

Florida

CDC (1993) surveyed 330 subjects living in the Florida Everglades and determined that average hair mercury concentrations were 1.3 µg/g.. The maximum value was 15.6 µg/g.

Wisconsin

Knobeloch et al. (1995) reporting on two individuals with blood mercury concentrations of 38 and >50 µg/g. found the individuals hair mercury concentrations were 11 and 12 µg/g.

Great Lakes Region

Gerstenberger et al. (1997) determined mean mercury concentrations were less than one µg/g. among 78 Ojibwa Tribal members. The maximum hair mercury concentration was 2.6 µg/g.

Alaska

Lazaret et al., (1991) reported hair mercury concentrations averaging 1.4 µg/g among 80 women of childbearing age. The maximum hair mercury concentrations were 15.2 µg/g.

Table 6-3
Hair Mercury Concentrations (ug Hg/gram hair or ppm) from Residents of Various Communities in the United States

Study	Community	Mean Concentration	Maximum Concentration	Additional Information on Study
Creason et al., 1978a	New York Metropolitan Area	Children (n=280); 0.67 ppm Adults (n=203); 0.77	Children, 11.3 ppm Adults, 14.0 ppm	Survey conducted in 1971 and 1972
Creason et al., 1978b	Four communities in New Jersey: Ridgewood, Fairlawn, Matawan and Elizabeth	Children (n=204), 0.77 ppm Adults (n=117), 0.78 ppm	Children, 4.4 ppm Adults, 5.6 ppm	Survey conducted in 1972 and 1973
Creason et al., 1978c	Birmingham, Alabama, and Charlotte, North Carolina	Children (n=322), 0.46 ppm Adults (n-117) 0.78 ppm	Children, 5.4 ppm; Adults, 7.5 ppm	Survey conducted in 1972 and 1973

Table 6-3 (continued)
Hair Mercury Concentrations (ug Hg/gram hair or ppm) from Residents of Various Communities in the United States

Study	Community	Mean Concentration	Maximum Concentration	Additional Information on Study
Airey, 1983	U.S. data cited by Airey, 1983. Community not identified.	1) Males (n=22), 2.7 ppm; 2). Females (n=16), 2.6 ppm; 3) Males and Females (24 subjects), 2.1 ppm; 4) Males and Females (31 subjects), 2.2 ppm; 5) Males and Females 924 subjects) 2.9 ppm; 6) Males and Females (79 subjects), 2.4 ppm.	1) 6.2 ppm 2) 5.5 ppm 3) 5.6 ppm 4) 6.6 ppm 5) 7.9 ppm 6) 7.9 ppm	
Airey, 1983	U.S. data cited by Airey, 1983 Community identified: LaJolla-San Diego	1) 2.4 ppm (13 men); 2) 2.7 ppm (13 women); 3) 2.3 ppm (8 subjects including men and women); 4) 2.9 ppm (17 subjects including men and women); 5) 2.6 ppm (5 subjects including men and women); 6) 2.8 ppm (30 subjects including men and women).	1) 6.2 ppm 2) 5.5 ppm 3) 4.5 ppm 5) 6.2 ppm 6) 6.6 ppm	
Airey, 1983	U.S. data cited by Airey, 1983. Area identified: Maryland	1) 1.8 ppm (11 subjects, men and women); 2) 1.5 ppm (11 subjects, men and women); 3) 2.3 ppm (11 subjects, men and women); 4) 1.9 ppm (33 subjects, men and women).	1) 3.8 ppm 2) 3.9 ppm 3) 4.5 ppm 4) 4.4 ppm	

Table 6-3 (continued)
Hair Mercury Concentrations (ug Hg/gram hair or ppm) from Residents of Various Communities in the United States

Study	Community	Mean Concentration	Maximum Concentration	Additional Information on Study
Airey, 1983	U.S. data cited by Airey, 1983 Community identified: Seattle.	1) 3.3 ppm (9 men); 2. 2.2 ppm (3 women); 3) 2.6 ppm (5 subjects men and women); 4) 1.5 ppm (3 subjects, men and women); 5) 3.8 ppm (8 subjects, men and women); 6) 3.0 ppm (16 subjects, men and women).	1) 5.6 ppm 2) 4.1 ppm 3) 5.6 ppm 4) 2.1 ppm 5) 7.9 ppm 6) 7.9 ppm	
Crispin-Smith et al., 1997	U.S., Communities and distribution not identified	0.48 ppm (1,431 individuals); 0.52 ppm (1009 individuals reporting some seafood consumption)	6.3 ppm	The 1009 individuals are a subset of the 1431 subjects.
Lasora et al., 1991	Nome, Alaska	1.36 ppm (80 women of childbearing age)	15.2 ppm	
Lasora et al., 1991	Sequim, Washington	0.70 ppm (7 women of childbearing age)	1.5 ppm	
Fleming et al., 1995	Florida Everglades	1.3 ppm (330 subjects, men and women)	15.6 ppm	To be included in the survey the subjects had to have consumed fish or wildlife from the Everglades.
Knobeloch et al., 1995	Wisconsin, urban	2 adults (1 man, 1 woman); values 11 and 12 ppm		

Table 6-3 (continued)
Hair Mercury Concentrations (ug Hg/gram hair or ppm) from Residents of Various Communities in the United States

Study	Community	Mean Concentration	Maximum Concentration	Additional Information on Study
Gerstenberger et al., 1997	Ojibwa Tribal members from the Great Lakes Region	47% > 0.28 ppm. Among individuals with values above the level of detection, the mean was 0.83 ppm based on 78 subjects	2.6 ppm	
Harnly et al., 1997	Native Americans living near Clear Lake, California.	68 Tribal members. Mean value: 0.64 ppm. 4 non-Tribal members. Mean value: 1.6 ppm	Maximum value for Tribal members: 1.8 ppm Maximum value for non-Tribal members: 2.3 ppm	

6.5.2.2 Summary of Data on Hair Mercury Concentrations

Available data indicate that mean mercury concentrations in the U.S. population are typically less than 3 µg/g and often less than 1 µg/g, although, maximum concentrations of more than 15 µg/g are reported. Hair mercury concentrations of greater than 10 µg/g have been associated with mercury exposure from fish. The shape of the distribution of hair mercury concentrations in the United States is not well documented. Comparison of data summarized by Airey (1983) on the association between frequency of fish meals, mean and range of hair mercury concentrations reveals (see Table 6-4):

- The arithmetic mean of hair mercury from the U.S. surveys is consistent with the lower bound of the range associated with fish ingestion rates of less than once a month to as frequent as once a week.

- The maximum values identified in the surveys are consistent with fish consumption of every week to every day.

Table 6-4
Association of Hair Mercury Concentrations (ug Hg/gram hair) with Frequency of Fish Ingestion by Adult Men and Women Living in 32 Locations within 13 Countries (Airey, 1983)

Frequency of Fish Meals	Arithmetic Mean	Range
Once a Month or Less	1.4	0.1-6.2
Twice a Month	1.9	0.2-9.2
Every Week	2.5	0.2-16.2
Every Day	11.6	3.6-24.0

6.6 Conclusions

6.6.1 Blood Mercury Levels

Mercury in blood is a reflection of exposures in recent days and weeks to environmental mercury. Typically blood mercury values are reported as total mercury, although chemically speciated mercury analyses often are included in reports published in the 1990s. Organic mercury in blood generally reflects methylmercury intake from fish and shellfish. At progressively higher dietary intakes of fish and shellfish, the fraction of total blood mercury that is organic mercury increases becoming more than 95% at high levels of fish consumption.

Blood mercury concentrations (µg Hg/L) in healthy populations are less than 3 µg/L (5 µg/kg packed cells and 0.5 µg/L serum) based on values published by the International Union for Pure and Applied Chemistry (1996). The U.S. EPA RfD is associated with a whole blood mercury concentration of 4 to 5 µg/L. The “benchmark dose” for methylmercury used in setting the RfD is 44 µg/L based on neurotoxic effects observed in Iraqi children exposed *in utero.*

There are no representative data on blood mercury for the U.S. population as a whole. In the United States (in the peer-reviewed literature published in the 1990s), blood mercury concentrations in the range of 50 to 95 µg/L have been reported and attributed to the consumption of fish and shellfish. Among groups of anglers and Native American Tribal groups, mean blood mercury levels in the range of 10 to 20 µg/L have been reported. Blood mercury concentrations greater than 20 µg/L and attributable to consumption of fish and shellfish have been identified among women of childbearing age in the United States.

6.6.2 Hair Mercury Levels

Mercury is incorporated in hair as it grows. Typically the centimeter of hair nearest the scalp reflects mercury exposure during the past month. The extent to which the predominant chemical species in hair is a function of methylmercury exposure depends on environmental exposure patterns. Methylmercury in the diet results in elevated hair mercury concentrations. Dietary sources documented to produce elevated hair mercury concentrations include fish, shellfish, and flesh from marine mammals.

There are no representative data on hair mercury concentrations for the U.S. population as a whole. Typical values in the United States are less than 1 µg/g. Maximum hair mercury concentrations of 15 µg/gram and higher have been reported in the United States. Hair mercury concentrations greater than 10 µg/gram have been reported for women of childbearing age living in the United States. U.S. EPA’s RfD is associated with a hair mercury concentration of approximately 1 µg/g. The “benchmark” dose is associated with a hair mercury concentration of 11.1 µg/g and is based on neurotoxic effects observed in Iraqi children exposed *in utero* to methylmercury.

7. CONCLUSIONS

- The results of the current exposure of the U.S. population from fish consumption indicate that most of the population consumes fish and is exposed to methylmercury as a result. Approximately 85% of adults in the United States consumer fish and shellfish at least once a month with about half of adults selecting fish and shellfish as part of their diets at least once a week (based on food frequency data collected among more than 19,000 adult respondents in the NHANES III conducted between 1988 and 1994). This same survey identified 1-2% of adults who indicated they consume fish and shellfish almost daily.

- For the modeled fish ingestion scenarios, the local emission sources are predicted to account for the majority of the total mercury exposure for water bodies close to the sources. This is particularly true for the hypothetical western site, where background and regional atmospheric contributions to the total mercury concentration in the water column are predicted to be lower.

- Consumption of fish is the dominant pathway of exposure to methylmercury for fish-consuming humans. There is a great deal of variability among individuals in these populations with respect to food sources and fish consumption rates. As a result, there is a great deal of variability in exposure to methylmercury in these populations. The anthropogenic contribution to the total amount of methylmercury in fish is, in part, the result of anthropogenic mercury releases from industrial and combustion sources which increases mercury body burdens in fish. As a consequence of human consumption of the affected fish, there is an incremental increase in exposure to methylmercury. Terrestrial exposures were evaluated in the modeling analysis; inorganic mercury species were predicted to be the dominant chemical species to which humans are exposed.

- In the nationally-based dietary surveys, the types of fish most frequently reported to be eaten by consumers are tuna, shrimp, and Alaskan pollock. The importance of these species is corroborated by U.S. National Marine Fisheries Service data on per capita consumption rates of commercial fish species.

- National surveys indicate that Asian/Pacific Islander-American and Black-American subpopulations report more frequent consumption of fish and shellfish than other survey participants.

- Superimposed on this general pattern of fish and shellfish consumption is freshwater fish consumption, which may pose a significant source of methylmercury exposure to consumers of such fish. The magnitude of methylmercury exposure from freshwater fish varies with local consumption rates and methylmercury concentrations in the fish. The modeling exercise indicated that some of these methylmercury concentrations in freshwater fish may be elevated as a result of mercury emissions from anthropogenic sources. Exposures may be elevated among some members of this subpopulation; these may be evidenced by analyses of blood mercury showing concentrations in excess of 10 micrograms per liter (µg/L) that have been reported among multiple freshwater fish-consumer subpopulations. The mean value of blood mercury in an Arkansas study was 10µg/L. Because general populations data on the distribution of blood mercury concentrations have not been gathered, it is not known how common blood mercury concentration above 10µg/L are.

- An assessment of consumption of fish and shellfish was based on data obtained from contemporary nationally based dietary surveys conducted by the United States government: the third National Health and Nutrition Examination Survey conducted between 1988 and 1994 (National Center for Health Statistics of the Centers for Disease Control) and the 1994 and 1995 Continuing Surveys of Food Intakes by Individuals (United States Department of Agriculture). Data on mercury concentrations in fish and shellfish were obtained from national database compiled by the National Marine Fisheries Service and the U.S. Environment Protection Agency.

  The results of the assessment show that the predicted average exposure among make and female fish consumers of reproductive age is 0.1 micrograms of methylmercury per kilogram of body weight per day based on a single day's estimate. The comparable 90th percentile estimate is approximately four times this level. Median "per user" fish/shellfish consumption values across these nationally representative surveys were between 73 and 79 grams/day based on single-day estimates. The comparable 90th percentile values ranged between 186 and 242 grams/day based on single-day estimates.

  The single-day estimates are used to project month-long fish/shellfish consumption when combined with frequency of fish/shellfish consumption estimates obtained from adult participants in NHANES III. The single-day estimates of fish/shellfish consumption provide portion sizes to estimated the impact of intermittent consumption of fish containing mercury at concentrations considerably above that commonly encountered in the commercial market, e.g., approximately 0.5 ppm and higher. Fish with mercury concentrations averaging over 0.5 ppm include swordfish and shark among marine fish and smallmouth bass, largemouth bass, channel catfish, walleye, and northern pike among freshwater fish.

- Exposure rates to methylmercury among fish-consuming children are predicted to be higher than for fish-consuming adults on a body weight basis. The 50th percentile exposure rate among fish-consuming children ages 3 through 6 years is approximately 0.3 micrograms per kilogram of body weight per day based on single day estimates. Predicted exposures at the 90th percentile are approximately three-times greater or 0.8 to one microgram of mercury per kilogram of body weight on a single day. Estimated month long mercury exposures among 3 through 6 year-old children are 0.03 at the 50th percentile and 0.17 at the 90th percentile using adult data to predict how often children consume fish and shellfish. It is uncertain how well the adult data are predictive for children because data for children are not available.

- Exposures among specific subpopulations including anglers, Asian-Americans, and members of some Native American Tribes indicate that their average exposures to methylmercury may be more than two-times greater than those experience by the average population.

- Predicted high-end exposures to methylmercury are caused by one or two factors or their combination: 1) high consumption rates of methylmercury contaminated fish, water and/or 2) consumption of types of fish which exhibit elevated methylmercury concentrations in their tissues. Of these two factors the former appears to be more significant for overall population exposures.

- Blood mercury concentrations and hair mercury levels are biomarkers used to indicate exposure to mercury. Inorganic mercury exposures occur occupationally and for some individuals through folk/hobby exposures to inorganic mercury. Dental restorations with silver-mercury amalgams can also contribute to inorganic mercury exposures. Methylmercury exposure is almost exclusively through consumption of fish, shellfish, and marine mammals. Occupational exposures to methylmercury are rare.

Data describing blood and/or hair mercury for a population representative of the United States do not exist, however, some data are available. Blood mercury concentrations, attributable to consumption of fish and shellfish, in excess of 30 µg/L have been reported in the United States. Hair mercury concentrations in the United States are typically less than 1µg/g, however, hair mercury concentration greater than 10µ/g have been reported for women of childbearing age living in the United States. U.S. EPA's RfD is associated with a blood mercury concentration of 4-5 µg/L and a hair mercury concentration of approximately 1µg/g. The "benchmark" dose is associated with mercury concentrations of 44µg/L in blood and 11.1 µg/g in hair. The "benchmark" dose for methylmercury is based on neurotoxic effects observed in Iraqi children exposed *in utero* to methylmercury.

- To improve the quantitative exposure assessment modeling component of the risk assessment for mercury and mercury compounds, U.S. EPA would need more and better mercury emissions data and measured data near sources of concern, as well as a better quantitative understanding of mercury chemistry in the emission plume, the atmosphere, soils, water bodies, and biota.

- To improve the exposure estimated based on surveys of fish consumption, more study is needed among potentially high-end fish consumers, which examines specific biomarkers indicating mercury exposure (e.g., blood mercury concentrations and hair mercury concentrations).

- A pharmacokinetic-based understanding of mercury partitioning in children is needed. Additional studies of fish intake and methylmercury exposure among children are needed.

8. RESEARCH NEEDS

- To improve the quantitative exposure assessment modeling component of the risk assessment for mercury and mercury compounds, U.S. EPA would need more and better mercury emissions data and measured data near sources of concern, as well as a better quantitative understanding mor mercury chemistry I the emission plume, the atmosphere, soils, water bodies, and biota.

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APPENDIX A

EXPOSURE PARAMETER JUSTIFICATIONS

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DISTRIBUTION NOTATION

A comprehensive uncertainty analysis was not conducted as part of this study. Initially, preliminary parameter probability distributions were developed. These are listed in Appendicies A and B. These were not utilized in the generation of quantative exposure estimates. They are provided as a matter of interest for the reader.

Unless noted otherwise in the text, distribution notations are presented as follows.

Distribution	Description
Log (A,B)	Lognormal distribution with mean A and standard deviation B
Log*(A,B)	Lognormal distribution, but A and B are mean and standard deviation of underlying normal distribution.
Norm (A,B)	Normal distribution with mean A and standard deviation B
U (A,B)	Uniform distribution over the range (A,B)
T (A,B,C)	Triangular distribution over the range (A,C) with mode of B

A. EXPOSURE MODEL PARAMETERS

This appendix describes the parameters used in the exposure modeling for the Mercury Study Report to Congress. For other environmental fate model parameters the reader is referred to Appendicies A-C of Volume 3.

A.1 Chemical Independent Parameters

Chemical independent parameters are variables that remain constant despite the specific contaminant being evaluated. The chemical independent variables used in this study are described in the following sections.

A.1.1 Basic Constants

Table A-1 lists the chemical independent constants used in the study, their definitions, and values.

Table A-1
Chemical Independent Constants

Parameter	Description	Value
R	ideal gas constant	8.21E-5 m^3-atm/mole-K
pa	air density	1.19E-3 g/cm^3
ua	viscosity of air	1.84E-4 g/cm-second
Psed	solids density	2.7 kg/L
Cdrag	drag coefficient	1.1E-3
κ	Von Karman's coefficient	7.40E-1
λ_2	boundary thickness	4.0

A.1.2 Receptor Parameters

Receptor parameters are variables that reflect information about potential receptors modeled in the study. These parameters include body weight, exposure duration, and other characteristics of potential receptors.

A.1.2.1 Body Weight

Parameter: BWa, BWc

Definition: Body weights (or masses) of individual human receptors

Units: kg

Receptor	Default Value (kg)
Child	17
Adult	70

Technical Basis:

The default values for children and adults are those assumed in U.S. EPA, 1990.

A.1.2.2 Exposure Duration

Parameter: ED

Definition: Length of time that exposure occurs.

Units: years

Receptor	Default Value (years)	Distribution	Range (years)
Child	18	U(1,18)	1-18
Adult	30	U(7,70)	7-70

Technical Basis:

The 18-year exposure duration for the child is based on U.S. EPA guidance for this study. For adults, the 30-year duration is the assumed lifetime of the facility (U.S. EPA, 1990). It should be noted for noncarcinogenic chemicals the exposure duration is not used in the calculations. The range and distribution are arbitrary to determine the relative sensitivity of this variable, when appropriate.

A.1.4 Exposure Parameters

Exposure parameters are variables that directly affect an individual's dose or intake of a contaminant. Such parameters include inhalation and ingestion rates of air, water and crops and the surface area of skin for the purposes of dermal contact scenarios.

A.1.4.1 Inhalation Rate

Parameter: INH

Definition: Rate of inhalation of air containing contaminants.

Units: m^3/day

Receptor	Default Value (m^3/day)	Distribution
Infant	5.14	T(1.7,5.14,15.4)
Child	16	T(2.9,16,53.9)
Adult	20	T(6,20,60)

Technical Basis:

The default value for infants is the central value of the distribution used for 1 year olds in Hanford Environmental Dose Reconstruction Project (HEDR) (1992) and is from Roy and Courtay (1991). The default value for children is based on U.S. EPA (1990). The default value for adults is that recommended in U.S. EPA (1991), which states that this value represents a reasonable upper bound for individuals that spend a majority of time at home.

The range for infants is that used for 1 year olds in HEDR (1992) and was determined by scaling the value 5.14 by 0.3 and 3.0, respectively. The range for children is the smallest range containing the values used for 5-, 10-, and 15-year-old children in HEDR (1992). The range for the adult was obtained by scaling the default value by the same numbers used for infants of 0.3 and 3.0 (we note that HEDR, 1992 used a slightly higher central value of 22 m^3/day).

To prevent a bias towards upper-end inhalation rates, triangular distributions were considered more appropriate than more arbitrary uniform distributions, with a most likely value equal to the default value.

A.1.4.2 Consumption Rates

Parameter: CPi, CAj

Definition: Consumption rate of food product per kg of body weight per day.

Units: g dry weight/kg BW/day

Food Type	Child (gDW/kgBW/day)	Adult (g DW/kg BW/day)
Leafy Vegetables	0.008	0.0281
Grains and cereals	3.77	1.87
Legumes	0.666	0.381
Potatoes	0.274	0.170
Fruits	0.223	0.570
Fruiting vegetables	0.120	0.064
Rooting Vegetables	0.036	0.024
Beef, excluding liver	0.553	0.341
Beef liver[a]	0.025	0.066
Dairy (milk)	2.04	0.599
Pork	0.236	0.169
Poultry	0.214	0.111
Eggs	0.093	0.073
Lamb[a]	0.061	0.057

[a] Only the 95-100 percentile of the data from TAS (1991) was nonzero.

Technical Basis:

All of the values reported above are given on a gram dry weight per kg of body weight per day basis. With the exception of the ingestion rates for adults for leafy vegetables and fruits, the values are either the 50-55 percentile (or the 95-100 percentile if the median was zero) of the data from Technical Assessment Systems, Inc. (TAS). The values for the percentiles were reported in g DW/kg of body weight per day.

TAS conducted this analysis of food consumption habits of the total population and five population subgroups in the United States. The data used were the results of the Nationwide Food Consumption Survey (NFCS) of 1987-88 conducted by the United States Department of Agriculture. The information in the NFCS was collected during home visits by trained interviewers using one-day interviewer-recorded recall and a two-day self-administered record. A stratified area-probability sample of households was drawn in the 48 contiguous states from April 1987 to 1988. More than 10,000 individuals provided information for the basic survey.

Each individual's intake of food was averaged across the 3 days of the original NFCS survey, and food consumption for each food group was determined for each individual. Percentiles were then computed for six population subgroups:

- U.S. population
- males ≥ 13 years
- females ≥ 13 years
- children 1-6 years
- children 7-12 years
- infants < 1 year.

The values for children in the previous table are based on the data for children between 7 and 12 year of age, while the adult values are for males older than 12 years of age. The males older than 12 years of age were chosen to represent the adult since rates for females are lower; this is recoganized to be somewhat conservative. The United States population rates include the rates of children which were considered inappropriate for the hypothetical adult receptors modeled in this analysis.

The values for leafy vegetables and fruits for adults are from (USU.S. EPA 1989).

A.1.4.3 Soil Ingestion Rate

Parameter: Cs

Definition: Amount of soil ingested daily.

Units: g/day

Receptor	Default Value (g/day)	Distribution	Range (g/day)
Pica Child	7.5	U(5,10)	5-10
Child	0.2	U(0.016,0.2)	0.016-0.2
Adult	0.1	U(0.016,0.1)	0.016-0.1

Technical Basis:

Soil ingestion may occur inadvertently through hand-to-mouth contact or intentionally in the case of a child who engages in pica. The default values for adults and non-pica children are those suggested for use in U.S. EPA (1989). More recent studies have found that these values are rather conservative. For example, Calabrese and Stanek (1991) found that average soil intake by children was found to range from 0.016 to 0.055 g/day. This range, in conjunction with the suggested U.S. EPA values, was used to obtain the ranges shown.

Several studies suggest that a pica child may ingest up to 5 to 10 g/day (LaGoy, 1987, U.S. EPA, 1989). This range was selected, and the midpoint was chosen as the default value.

A.1.4.4 Groundwater Ingestion Rate

Parameter: Cw

Definition: The amount of water consumed each day.

Units: L/day

Receptor	Default Values (L/day)	Distribution
Child	1.0	Log*(0.378; 0.079)
Adult	2.0	Log*(0.1; 0.007)

Technical Basis:

The default values for children and adult are those also suggested in U.S. EPA (1989) and were first published by the Safe Drinking Water Committee of the National Academy of Sciences (NAS, 1977).

The distributions are those computed in Roseberry and Burmaster (1992). In that paper, lognormal distributions were fit to data collected in a national survey for both total water intake and tap water intake by children and adults. These data were originally gathered in the 1977-1978 Nationwide Food Consumption Survey of the United States Department of Agriculture and were analyzed by Ershow and Cantor (1989).

In Roseberry and Burmaster (1992), distributions were fit to the intake rates for humans ages 0-1 year, 1-11 years, 11-20 years, 20-65 years and older than 65 years. The distribution for children ages 1-11 was chosen for the child's distribution given in the previous table and the distribution for adults ages 20-65 was used for the adult. For the purpose of the present analysis, the tap water intake was deemed more appropriate than total water intake. The total water intake included water intrinsic in foods that are accounted for in the agricultural pathways, while the tap water intake was the sum of water consumed directly as a beverage and water added to foods and beverages during preparation.

The minima and maxima were selected as the 2.5 and 97.5 percentiles, respectively.

A.1.4.5 Fish Ingestion Rate

Parameter: Cf

Definition: Quantity of locally - caught fish ingested per day.

Units: g/day

Receptor	Default Value (g/day)
High End Fisher	60
Child of high end fisher	20
Recreational Angler	30

Technical Basis:

Because of the bioaccumulation of methylmercury in fish, the fish ingestion rate is an important parameter for modeling mercury exposure. Fish consumption rates are difficult to determine for a general population study because individual fish ingestion rates vary widely across the United States. This animal protein source may be readily consumed or avoided on a seasonal, social, economic or demographic basis. Ideally, for an actual site, specific surveys identifying the type, source, and quantity of fish consumed by area residents would be used. Within the context of this study, it is not possible to characterize this variability completely.

For this part of the assessment, individuals in three broad groups of exposed populations will be considered: high end fishers, recreational anglers and the general population. For the general population, no commercial distribution of locally caught fish was assumed. All consumers of locally-caught fish were assumed to be recreational anglers or subsistence fishers.

In U.S. EPA's 1989 Exposure Factors Handbook, fish consumption data from Puffer (1981) and Pierce et al. (1981) are suggested as most appropriate for fish consumption of recreational anglers from large water bodies. The median of this subpopulation is 30 g/day with a 90th percentile of 140 g/day (340 meals/year). The median was used as the surrogate value for recreational anglers.

For subsistence fishers, human fish consumption data were obtained from the report of the Columbia River Inter-Tribal Fish Commission (1994), which estimated fish consumption rates for members of four tribes inhabiting the Columbia River Basin. The estimated fish consumption rates were based on interviews with 513 adult tribe members who lived on or near the reservation. The participants had been selected from patient registration lists provided by the Indian Health Service. Adults interviewed provided information on fish consumption for themselves and for 204 children under 5 years of age.

During the study fish were consumed by over 90% of the population with only 9% of the respondents reporting no fish consumption. Monthly variations in consumption rates were reported. The average daily consumption rate during the two highest intake months was 107.8 grams/day, and the daily consumption rate during the two lowest consumption months was 30.7 grams/day. Members who were aged 60 years and older had an average daily consumption rate of 74.4 grams/day. During the past two decades, a decrease in fish consumption was generally noted among respondents in this survey. The maximum daily consumption rate for fish reported for this group was 972 grams/day.

The mean daily fish consumption rate for the total adult population (aged 18 years and older) was reported to be 59 grams/day. The mean daily fish consumption rate for the adult females surveyed was 56 g/day and the mean daily fish consumption rate for the adult males surveyed was 63 grams. A value of 60 grams of fish per day was selected for the subsistence angler modeled in this report.

Other fish consumption rate studies for specific subpopulations (i.e., anglers and subsistence consumers) have been conducted. These studies are briefly described in Volume IV. These studies demonstrate the wide range of fish consumption rates exhibited across the U.S. population. They also tend to corroborate the estimates to be used in this analysis. These analyses also illustrate the difficulty in determining average and high-end consumption rates for subpopulations considered to be more likely to consume more fish.

In the lacustrine scenarios of this assessment, all fish were assumed to originate from the lakes, which are considered to represent several small lakes that may be present in a hypothetical location.

The effects of fish preparation for food on extant mercury levels in fish have also been evaluated (Morgan et al., 1994). Total mercury levels in walleye were found to be constant before and after preparation; however, mercury concentrations in the cooked fish were increased 1.3 to 2.0 times when compared to mercury levels in the raw fish. It was suggested that this increase was probably due to water and fat loss during cooking and fish skin removal. A preparation factor adjustment was noted but not implemented in this analysis because human consumption levels were measured on uncooked fish. For more information see Volume IV.

A.1.4.6 Contact Fractions

Parameter: FPi, Faj

Definition: that fraction of the food type grown or raised on contaminated land

Units: Unitless

Food	Subsistence Farmer	Rural Home Gardener/ Subsistence Fisher	Urban Gardener	Comment
Grains	1	0.667	0.195	Values are for corn from Table 2-7 in U.S. EPA (1989)
Legumes	1	0.8	0.5	Values are for peas from Table 2-7 in U.S. EPA (1989).
Potatoes	1	0.225	0.031	Values are for total fresh potatoes from Table 2-7 in U.S. EPA (1989).
Root Vegetables	1	0.268	0.073	Values are for carrots from Table 2-7 in U.S. EPA (1989).
Fruits	1	0.233	0.076	Values are for Total non-citrus fruit from Table 2-7 in U.S. EPA (1989).
Fruiting Vegetables	1	0.623	0.317	Values are for tomatoes from Table 2-7 in U.S. EPA (1989).
Leafy Vegetables	1	0.058	0.026	Values are for lettuce from U.S. EPA (1989).
Beef	1	0	0	
Beef liver	1	0	0	
Dairy	1	0	0	
Pork	1	0	0	
Poultry	1	0	0	
Eggs	1	0	0	
Lamb	1	0	0	

Technical Basis:

The values for the subsistence farmer are consistent with the assumptions regarding this scenario. The values for the gardeners are from U.S. EPA (1989), per U.S. EPA guidance. Because it is assumed that only the subsistence farmers will consume contaminated animal products, the contact fractions for gardeners is 0 for consumption of local animal products.

A.2 Chemical Dependent Parameters

Chemical dependent parameters are variables that change depending on the specific contaminant being evaluated. The chemical dependent variables used in this study are described in the following sections.

A.2.1 Basic Chemical Properties

The following sections list the chemical properties used in the study, their definitions, and values.

A.2.1.1 Molecular Weight

Parameter: Mw

Definition: The mass in grams of one mole of molecules of a compound.

Units: g/mole

Chemical	Default Value (g/mole)
Hg^0, Hg^{2+}	201
Methylmercury	216
Methyl mercuric chloride	251
Mercuric chloride	272

A.2.1.2 Henry's Law Constant

Parameter: H

Definition: Provides a measure of the extent of chemical partitioning between air and water at equilibrium.

Units: atm-m^3/mole

Chemical	Default Value (atm-m^3/mole)
Hg^0	7.1×10^{-3}
Hg^{2+} ($HgCl_2$)	7.1×10^{-10}
Methylmercury	4.7×10^{-7}

Technical Basis:

The higher the Henry's Law Constant, the more likely a chemical is to volatilize than to remain in the water. The value for Hg^0 is from Iverfeldt and Persson (1985), while the other values are from Lindquist and Rodhe (1985).

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APPENDIX B

ESTIMATED NATIONAL AND REGIONAL POPULATIONS OF WOMEN OF CHILD-BEARING AGE: UNITED STATES, 1990

Estimated National and Regional Populations of Women of Child-Bearing Age: United States, 1990

Because methylmercury is a developmental toxin, the subpopulation judged of particular concern in this *Mercury Study: Report to Congress* was women of child-bearing age. Estimates of the size of the population of women of reproductive age, number of live births, number of fetal deaths, and number of legal abortions can be used to predict the percent of the population and number of women of reproductive age who are pregnant in a given year. This methodology has been previously used in the Agency for Toxic Substances and Disease Registry's (ATSDR's) Report to Congress on *The Nature and Extent of Lead Poisoning in Children in the United States* (Mushak and Crocetti, 1990).

The estimates of number of women of child-bearing age calculated for this *Mercury Study: Report to Congress* were prepared by Dr. A.M. Crocetti under purchase order from the EPA Office of Air Quality, Planning and Standards (OAQPS). The techniques used by Dr. Crocetti parallel those used to prepared the 1984 estimates for ATSDR. To estimate the size of this population on a national basis *Vital and Health Statistics* data for number of live births (National Center for Health Statistics of the United States, 1990; Volume I, Natality, Table 1-60, pages 134-140), and fetal deaths (National Center for Health Statistics of the United States, 1990; Volume II, Mortality; Table 3-10, pages 16, 18, and 20). Fetal wastage, that is, spontaneous abortions prior to 20 weeks of gestation were not considered since no systematically collected, nationally based data exist.

The estimate of number of women of child-bearing age includes some proportion of women who will never experience pregnancy. However, substitution of the number of pregnancies in a given year provides some measure of assessing the size of the surrogate population at risk. Estimates of the size of the population were based on "Estimates of Resident Population of the United States Regions and Divisions by Age and Sex" (Byerly, 1993). The Census data for 1990 were grouped by age and gender. The sizes of these populations are shown in Table B-1.

Women ages 15 through 44 are the age group of greatest interest in identifying a subpopulation of concern for the effects of a developmental toxin such as methylmercury. This population consisted of 58,222,000 women living within the contiguous United States. This population was chosen rather than for the total United States (population 58,620,000 women ages 15 through 44 years) because the dietary survey information from CSFII 89-91 did not include Hawaii and Alaska. Based on estimates of fish consumption data for Alaska by Nobmann et al. (1992) the quantities of fish eaten by Alaskans exceeds those of the contiguous U.S. population. It is also estimated that residents of the Hawaiian Islands also have fish consumption patterns that differ from those of the contiguous United States.

The number of pregnancies per year was estimated by combining the number of live births, number of fetal deaths (past 20 weeks of gestation) and the number of legal abortions. The legal abortion data were based on information published by Koonin et al. (1993) in *Morbidity and Mortality Weekly Report*. These totals are presented in Table B-2. As noted in this table, the total of legal abortions includes those with unknown age which were not included in the body of each table entry. There were 2,929 such cases for the United States in 1990 or 0.2% of all legal abortions. Another complication in the legal abortion data was for the age group 45 and older. The available data provide abortion data for 40 years and older only. To estimate the size of the population older than 45 years, the number of legal abortions for women age 40 years and older were allocated by using the proportions of Live Births and Fetal Deaths for the two age groups 40-44 and 45 and older.

It was estimated that within the contiguous United States 9.5% of women ages 15 to 44 years were pregnant in a given year. The total number of live births reported in 1990 for this age group was 4,112,579 with 30,974 reported fetal deaths and 1,407,830 reported legal abortions. The estimated number of total pregnancies for women ages 15 to 44 years was 5,551,383 in a population of 58,222,000 women.

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Table B-1

Resident Population of the United States and Divisions, April 1, 1990
Census by Gender and Age; in Thousands, including Armed Forces Residing in Region

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
United States	248,710	53,853	117,610	77,248
Male	121,239	27,570	58,989	34,680
Female	127,471	26,284	58,620	42,567
% Female	51.3	48.8	49.8	55.1

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
Contiguous United States	247,052	53,462	116,772	76,817
Male	120,385	27,369	58,548	34,467
Female	126,667	26,094	58,222	42,348
% Female	51.3	48.8	49.9	55.1

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
New England	13,207	2,590	6,379	4,239
Male	6,380	1,327	3,174	1,878
Female	6,827	1,264	3,202	2,361
% Female	51.7	48.8	50.2	55.7

Table B-1 (continued)

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 45 Years of Age**
Middle Atlantic States	37,602	7,471	17,495	12,638
Male	18,056	3,824	8,676	5,554
Female	19,547	3,645	8,818	7,083
% Female	52	49	50	56

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
E North Central	42,009	9,233	19,596	13,180
Male	20,373	4,728	9,744	5,899
Female	21,636	4,505	9,851	7,279
% Female	51.5	48.8	50.3	55.2

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
West North Central	17,660	3,967	8,017	5,676
Male	8,599	2,032	4,020	2,546
Female	9,061	1,935	3,997	3,129
% Female	51.3	48.8	49.9	55.1

Table B-1 (continued)

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
South Atlantic	43,567	8,864	20,579	14,122
Male	21,129	4,531	10,279	6,321
Female	22,438	4,333	10,301	7,804
% Female	51.5	48.9	50.1	55.3

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
East South Central	15,176	3,316	7,037	4,823
Male	7,301	1,698	3,472	2,132
Female	7,875	1,618	3,565	2,692
% Female	51.9	48.8	50.7	55.8

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
West South Central	26,703	6,366	12,687	7,651
Male	13,061	3,256	6,359	3,445
Female	13,641	3,110	6,328	4,204
% Female	51.1	48.9	49.9	54.9

Table B-1 (continued)

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
Mountain States	13,659	3,313	6,435	3,910
Male	6,779	1,696	3,259	1,825
Female	6,880	1,616	3,176	2,087
% Female	50.4	48.8	49.4	53.4

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
West North Central	17,660	3,967	8,017	5,676
Male	8,599	2,032	4,020	2,546
Female	9,061	1,935	3,997	3,129
% Female	51.3	48.8	49.9	55.1

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
Pacific (5 States including Alaska and Hawaii)	39,127	8,734	19,394	11,011
Male	19,562	4,476	10,004	5,083
Female	19,565	4,258	9,379	5,929
% Female	50.0	48.8	48.4	53.8

Table B-1 (continued)

Resident Population of the United States and Divisions, April 1, 1990 Census by Gender and Age; in Thousands, including Armed Forces Residing in Region.				
Division/ Gender	**Total**	**< 15 Years of Age**	**15-44 Years of Age**	**> 44 Years of Age**
Pacific (Washington, Oregon and California only)	37,469	8,343	18,546	10,580
Male	18,708	4,275	9,563	4,870
Female	18,761	4,068	8,981	5,710
% Female	50.1	48.8	48.4	54.0

Table B-2
Pregnancies by Outcome for Resident Females by Divisions and States,
U.S. 1990, by Age

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
United States		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years*****
	Females	127,471,000	26,284,000	58,620,000	42,567,000
	Live births	4,158,212	11,657	4,144,917	1,638
	Fetal Deaths	31,386	174	31,176	36
	Legal Abortions	1,429,577	11,819	1,413,992	837
	Total Pregnancies	5,619,175	23,650	5,590,085	2,511
	% Pregnant		-	9.5	-

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
Contiguous United States		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	126,667,000	26,094,000	58,222,000	42,348,000
	Live births	4,125,821	11,615	4,112,579	1,627
	Fetal Deaths	31,183	173	30,974	36
	Legal Abortions	1,423,340	11,765	1,407,830	833
	Total Pregnancies	5,580,344	23,553	5,551,383	2,496
	% Pregnant	-	-	9.5	-

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
New England		**Total****	**< 15 Years**	**15-44 Years**	**>44 Years**
	Females	6,827,000	1,264,000	3,202,000	2,361,000
	Live births	201,173	270	200,827	76
	Fetal Deaths	1,226	4	1,220	2
	Legal Abortions	78,347	487	77,358	37
	Total Pregnancies	280,746	761	279,405	115
	% Pregnant	-	-	8.7	-

Table B-2 (continued)

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
Middle Atlantic		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	19,547,000	3,645,000	8,818,000	7,083,000
	Live births	591,826	1,305	590,238	283
	Fetal Deaths	5,653	25	5,622	6
	Legal Abortions	252,599	1,912	250,484	157
	Total Pregnancies	850,078	3,242	846,344	446
	% Pregnant			9.6	

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
East North Central		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	21,636,000	4,505,000	9,851,000	7,279,000
	Live births	675,512	1,838	673,449	225
	Fetal Deaths	4,555	14	4,537	4
	Legal Abortions	166,897	1,056	165,434	109
	Total Pregnancies	846,964	2,908	843,420	338
	% Pregnant			8.6	

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
West North Central		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	9,061,000	1,935,000	3,997,000	3,129,000
	Live births	270,331	457	269,792	82
	Fetal Deaths	1,741	6	1,733	2
	Legal Abortions	57,219	398	56,562	30
	Total Pregnancies	329,291	861	328,087	114
	% Pregnant		-	8.2	-

Table B-2 (continued)

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
South Atlantic		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	22,438,000	4,333,000	10,301,000	7,804,000
	Live births	700,285	2,644	697,424	217
	Fetal Deaths	6,453	57	6,389	7
	Legal Abortions	238,538	2,242	235,536	123
	Total Pregnancies	945,276	4,943	939,349	347
	% Pregnant		-	9.1	-

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
East South Central		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	7,875,000	1,618,000	3,565,000	2,692,000
	Live births	236,374	1,143	235,195	36
	Fetal Deaths	2,954	25	2,027	2
	Legal Abortions	53,919	662	53,030	19
	Total Pregnancies	292,347	1,830	290,252	57
	% Pregnant		-	8.1	-

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
West South Central		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	13,641,000	3,110,000	6,328,000	4,204,000
	Live births	472,721	1,852	470,715	154
	Fetal Deaths	3,258	21	3,234	3
	Legal Abortions	122,261	781	121,100	90
	Total Pregnancies	598,240	2,654	595,049	247
	% Pregnant		-	9.4	-

Table B-2 (continued)

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
Mountain		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	6,880,000	1,616,000	3,176,000	2,087,000
	Live births	242,829	500	242,235	94
	Fetal Deaths	1,492	6	1,483	3
	Legal Abortions	50,880	288	50,330	31
	Total Pregnancies	295,201	794	294,048	128
	% Pregnant		-	9.3	-

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
Pacific (5 states including Alaska and Hawaii)		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	19,565,000	4,258,000	9,379,000	5,929,000
	Live births	767.161	1,648	765,042	471
	Fetal Deaths	4,954	16	4,931	7
	Legal Abortions	408,917	3,993	404,158	241
	Total Pregnancies	1,181,032	5,657	1,174,131	719
	% Pregnant		-	12.5	-

Pregnancies by Outcome for Resident Females by Divisions and States, U.S. 1990, by Age*					
Pacific (Washington, Oregon, and California)		**Total****	**< 15 Years**	**15-44 Years**	**> 44 Years**
	Females	18,761,000	4,068,000	8,981,000	5,710,000
	Live births	734,770	1,606	732,704	460
	Fetal Deaths	4,751	15	4,729	7
	Legal Abortions	402,680	3,939	397,996	237
	Total Pregnancies	1,142,201	5,560	1,135,429	704
	% Pregnant	-	-	12.6	-

APPENDIX C
ANALYSIS OF MERCURY LEVELS IN FISH AND SHELLFISH REPORTED IN *NATIONAL MARINE FISHERIES SERVICE SURVEY OF TRACE ELEMENTS IN THE FISHERY RESERVE*

C.1 Introduction

Some reviewers of data on the levels of mercury in fish and shellfish have expressed concern about the methods used to handle "nondetects" by the investigators who originally reported the data on the concentrations of mercury in fish and shellfish tissues. Specifically, these reviewers have expressed concern about the potential impact that different methods of handling nondetects may have on the reported mean concentrations of mercury. The purpose of this memo is to report the results of a data analysis performed on the nondetects in the mercury data reported in the report *National Marine Fisheries Service Survey of Trace Elements in the Fishery Reserve*, hereinafter referenced as the NMFS Report.

The major conclusion of this analysis is that different methods of handling nondetects have negligible impact on the reported mean concentrations. This conclusion follows from two findings from the data analysis, set forth below. First, when mean mercury levels are relatively "large", there are few, if any, nondetects, so the methodology employed to handle nondetects is irrelevant. Second, when mean mercury levels are small, there are relatively large numbers of nondetects. However, the differences between different methods of handling nondetects result in small differences in the resultant mean values.

The NMFS Report reports number of samples, number of nondetects, and mean, standard deviation, minimum and maximum mercury level in ppm for 1,333 combinations of fish/shellfish species, variety, location caught, and tissue. Of these, 777 correspond to fish/shellfish species for which we have mercury concentration data. These 777 combinations form the basis for the analyses reported in this memorandum. They represent 5,707 analyses of fish and shellfish tissues for mercury, of which 1,467, or 26 percent, are reported as nondetects. Because the mercury concentration data is used in our analyses at the species level, not at the more detailed species/variety/location/tissue level, we have aggregated, or pooled, the 777 combinations to 35 different species for the purposes of this analysis.

In the following sections, we first discuss various methods of handling nondetects in calculating mean mercury concentrations, then the analysis method adopted, and finally the results of that analysis.

C.2 Methods for Handling the Detection Limits

There are five methods commonly used to handle values below the detection limits in calculating the mean mercury levels.

1. *All nondetects are treated as being equal to 0.* The total number of samples for which mercury was measured is used in the mean calculation and it is assumed that the concentration of mercury is 0.000 whenever the chemical analysis was reported as "not detected". This approach may lead to an underestimation of the true mean.

2. *All nondetects are excluded from the calculation of the mean.* The mean is calculated as if these samples were not selected. The number of nondetects is subtracted from the total number of samples for which mercury was measured, and the resulting number is used to calculate the mean. This method may overestimate the true mean and always yields a mean estimate greater than that obtained by method 1 (see formulae in Addendum A).

3. *All nondetects are replaced with a fixed value, usually one-half of the detection limit.* This method is the most widely used and accepted of the five methods. It is difficult to know whether this method will lead to an underestimation or to an overestimation of the true mean. But it will always lead to an estimate that falls between the estimates obtained from method 1 and method 2.

4. *All nondetects are replaced with simulated mercury levels randomly selected in the interval (0, detection limit) according to an appropriate statistical distribution.* This method is close in spirit to method 3 and, like method 3, will lead to an estimate falling between estimates obtained from method 1 and method 2.

5. *All nondetects are replaced with the detection limit.* This method may overestimate the mean as all nondetects are smaller or equal to the detection limit. The mean calculated by method 5 will also be between the means obtained from method 1 and method 2.

The NMFS Report says that method 2 -- nondetects dropped from the calculation -- was used to calculate their reported mean mercury levels. However, an examination of their data indicates that the investigators did not always use method 2. It appears that other methods, including method 1 -- nondetects set equal to zero -- may have sometimes been used.

C.3 Method of Analysis

The approach adopted amounts to comparing means obtained by two different methods. Since we do not have access to the raw data, it was necessary to first assume that the reported mean mercury levels were calculated by one of the five methods mentioned above. Then we calculated the mean that would have been obtained if another method had been used.

Although it is possible to consider all ten possible combinations of two methods that can be obtained from the five under analysis, we have confined ourselves to the case where the other methods are compared with method 3, the latter being the most commonly used in such situations. The following three scenarios are studied:

- The reported means are assumed to have been calculated by method 1. The corresponding mean mercury levels that would have been obtained by method 3 were then calculated. The two sets of corresponding means are then compared. The calculation method is reported in Addendum A.

- The above analysis was repeated for method 2 and method 3.

- The above analysis was repeated for method 5 and method 3. It should be noted that if the reported mean is 0 and is assumed to be obtained by method 5 then method 3 might yield a negative value. In that case the mean was set to 0.000.

It is unlikely that method 4 was used to calculate the reported means since this would likely have appeared in the NMFS report. Therefore method 4 is ruled out of this analysis. To be able to calculate the mean mercury level by method 3, a value for the limit of detection is needed. We have been told that the limit of detection was 0.100 ppm. However, the data reported in the NMFS Report have numerous reported positive values less than 0.100 ppm. We therefore used the lowest of all detected analytical values as the presumed limit of detection. This value is 0.010 ppm.

Addendum B lists and graphs the mean mercury levels in ppm by fish and shellfish species, as reported by NMFS, then as calculated according to the methodology described above. That is, the mean mercury level that would be obtained by method 3, assuming NMFS used method 1 is presented, followed by the other two comparisons listed above. Then the mean differences between pairs of methods are presented.

C.4 Data Analysis Results

The calculations comparing method 1 -- nondetects dropped -- and method 3 -- nondetects set to one-half the detection limit, viz., 0.005 -- are reported in Figure C-1a and C-1b. The straight line in Figure C-1a is the line y = x; points on the line correspond to mean values that are the same for both methods. All points are on the line y = x, or nearly on it; the two methods yield identical results for most species. This result follows from the fact that when mean mercury levels are relatively large, very few nondetects were reported (see Figure C-4a).

In order to have a better assessment of the magnitude of the differences between method 1 and method 3, we plotted the differences between the two methods versus method 1 in Figure C-1b. The differences between methods 1 and 3 are never as high as 0.004 ppm. Further, they never exceed 0.001 ppm when the mean is above 0.200 ppm.

Figure C-1a
Mercury Levels from the Pooled Dataset Method 3 vs. Method 1

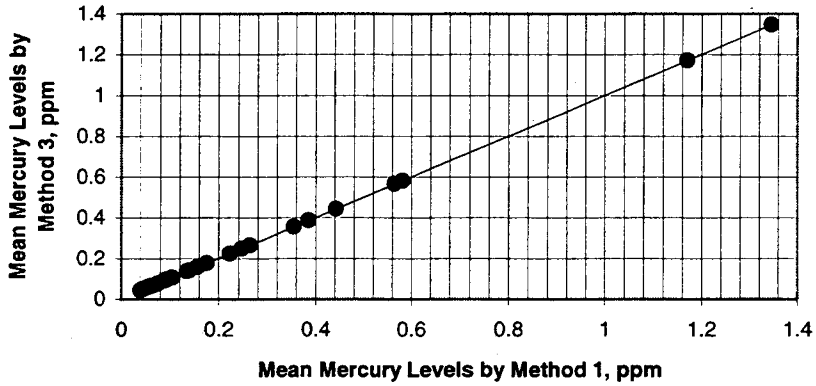
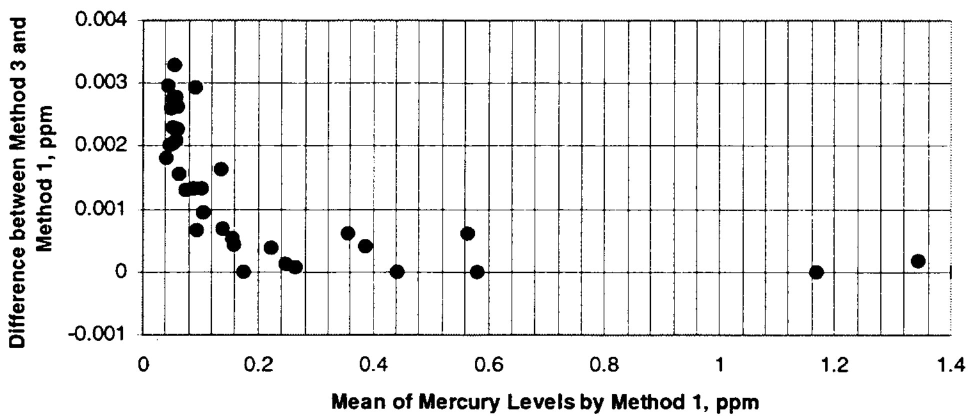


Figure C-1b
Comparison of Mercury Levels Between Method 3 and Method 1, Based on Differences from the Pooled Dataset



The results comparing methods 2 and 3 are in Figures C-2a and C-2b. They lead to the same conclusions as the comparison of methods 1 and 3. The differences between methods 2 and 3 never exceed 0.030 ppm in magnitude. Because the differences between methods 2 and 3 are an order of magnitude greater than the other two comparisons, it was decided to investigate the larger differences between these methods to see if there were any significant patterns.

The results comparing methods 5 and 3 are in Figures C-3a and C-3b. They lead to the same conclusions as the two previous comparisons. The differences between methods 5 and 3 never exceed 0.003 ppm in magnitude. They never exceed 0.001 ppm when the mean mercury level is above 0.200 ppm.

These results follow from the fact that the number of nondetects is especially high when the reported mean is very small. When that mean is larger, there are very few nondetects, so that all methods yield virtually the same results. This phenomenon is well illustrated in Figures C-4a and C-4b, which present the number and percentage of nondetects against the mean mercury levels, respectively.

Figure C-2a
Mercury Levels from the Pooled Dataset: Method 3 vs. Method 2

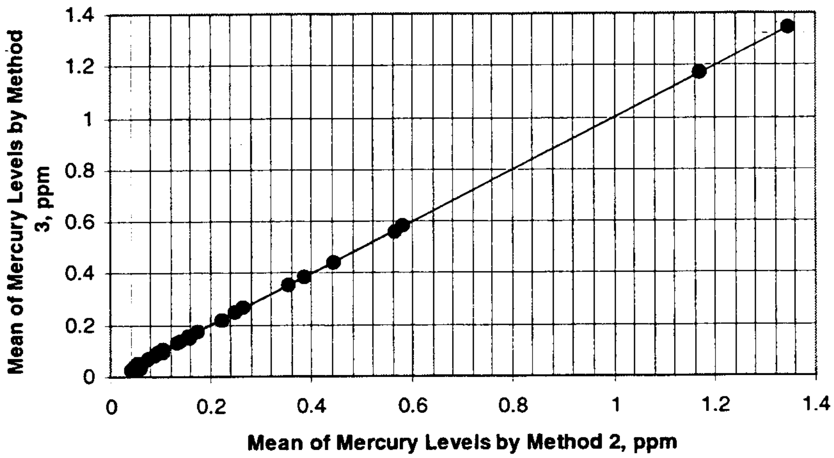


Figure C-2b
Comparison of Mercury Levels Between Method and Method 2, from the Pooled Dataset

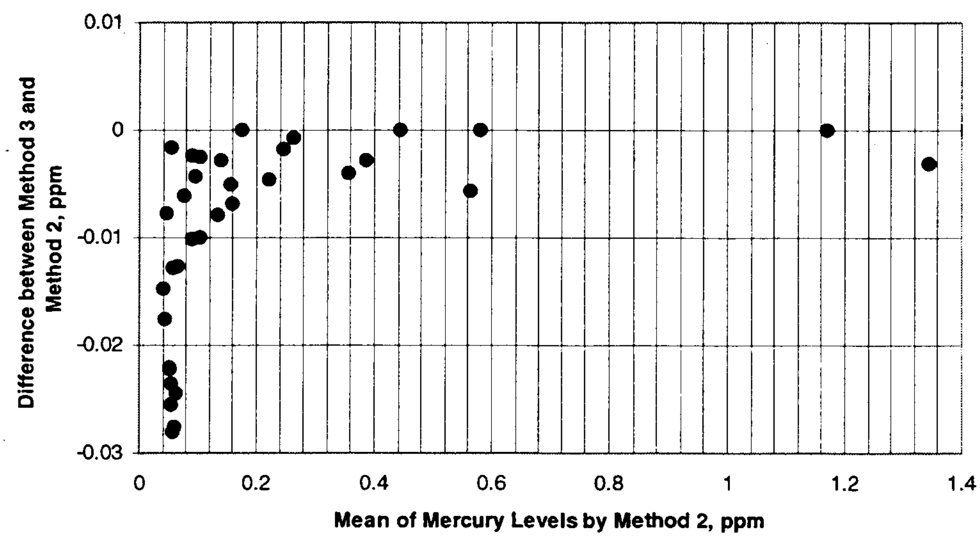


Figure C-3a
Mercury Levels from the Pooled Dataset: Method 3 vs Method 5

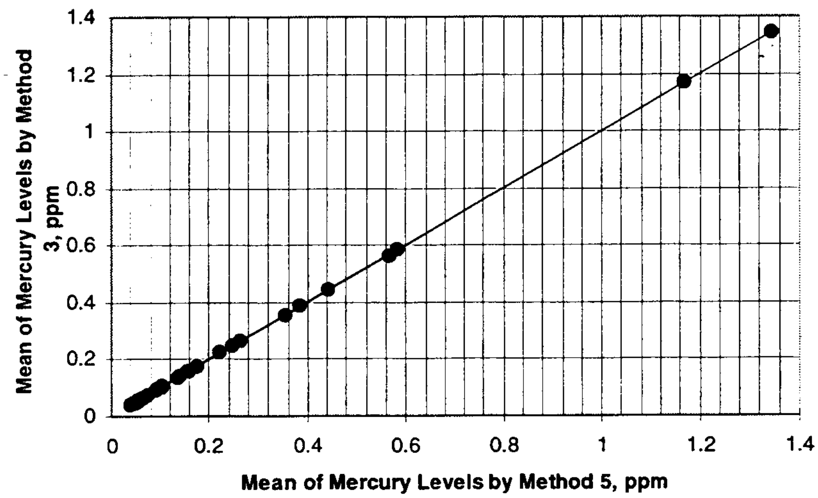


Figure C-3b
Comparison of Mercury Levels Between Method 3 and Method 5, from the Pooled Dataset

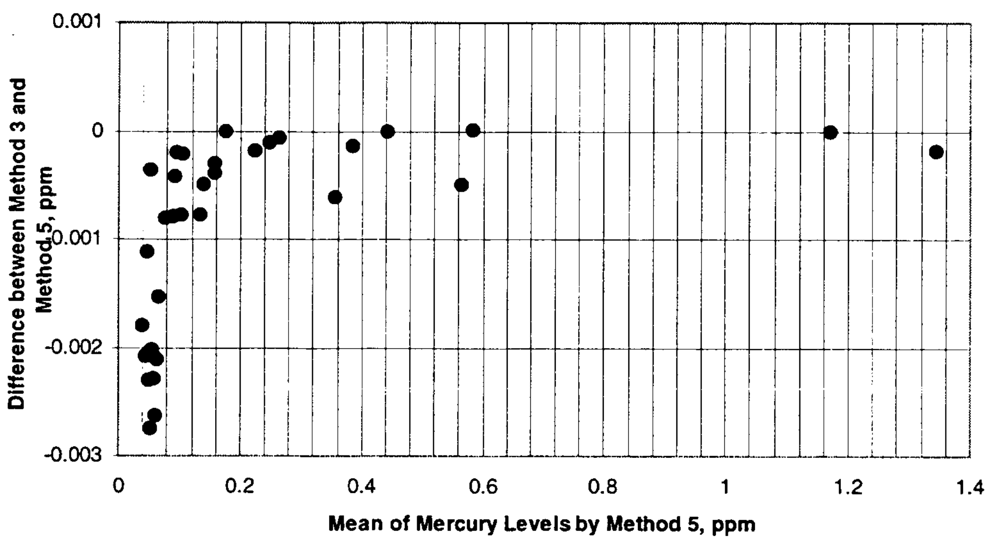


Figure C-4a
Number of Nondetects vs Mean Mercury Level

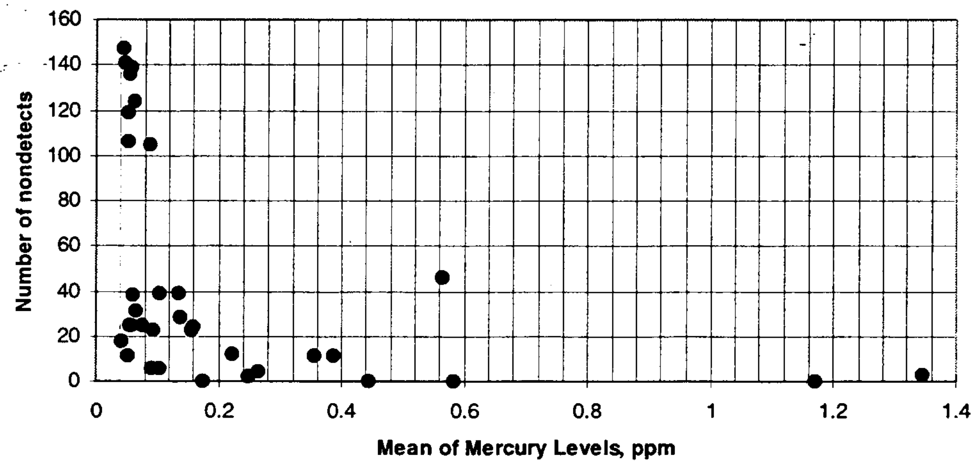
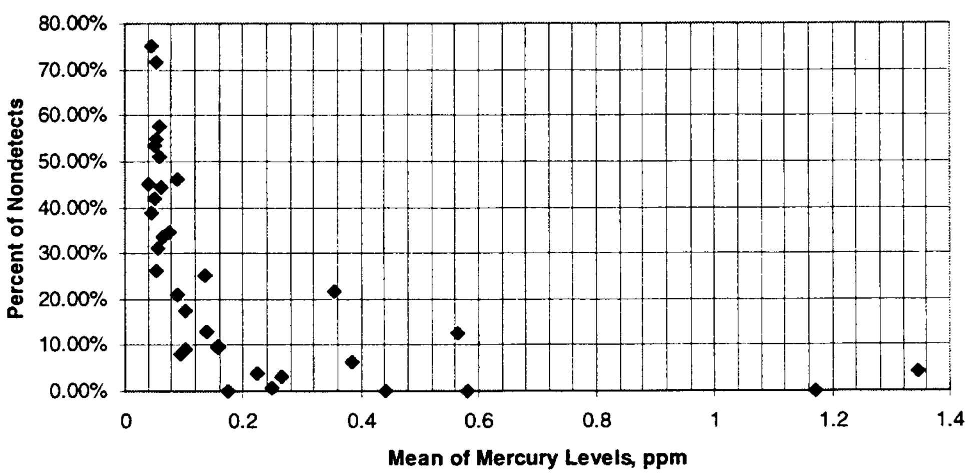


Figure C-4b
Percent of Nondetects vs Mean of Mercury Levels from the Pooled Dataset



ADDENDUM A

This addendum provides the formulae used to calculate the mean Mercury levels according to the four methods used in the analysis.

Let N_0 be the total number of samples for which the fish was measured, N_d the total number of samples in which no Mercury was detected and d_0 the limit of detection. Suppose that x_i stands for the Mercury level (ppm) detected in the i^{th} sample and that $\overline{X}_1, \overline{X}_2, \overline{X}_3$ and $\overline{X}_5$ are the mean Mercury levels calculated by methods 1,2,3 and 5 respectively. Then we have that,

$$\overline{X}_1 = \frac{1}{N_0} \sum_{i=1}^{N_0 - N_d} x_i \,, \quad \overline{X}_2 = \frac{1}{N_0 - N_d} \sum_{i=1}^{N_0 - N_d} x_i$$

$$\overline{X_3} = \frac{1}{N_0} \left(\sum_{i=1}^{N_0 - N_d} x_i + N_d d_0 \;/\; 2 \right), \quad \overline{X}_5 = \frac{1}{N_0} \left(\sum_{i=1}^{N_0 - N_d} x_i + N_d d_0 \right)$$

Let $\overline{X}_{3/1}$, $\overline{X}_{3/2}$ and $\overline{X}_{3/5}$ be the means calculated by method 3 under the assumption that the reported data are calculated by method 1, 2 and 5 respectively. These conditional means are obtained as follows:

$$\overline{X}_{3/1} = \frac{N_d \overline{X}_1 + N_d \times d_0 \div 2}{N_0},$$

$$\overline{X}_{3/2} = \frac{(N_0 - N_d)\overline{X}_2 + N_d \times d_0 \div 2}{N_0}$$

and

$$\overline{X}_{3/5} = \frac{N_0 \overline{X}_5 - N_d \times d_0 \div 2}{N_0}.$$

ADDENDUM B

Mercury Levels by Species

NMFS Data:
Table and Graphs

Comparisons of Different Methods of Handling Nondetects:
Table and Graphs

Table C-1

Records in NMFS Report for which the difference between Method 3 and Method 2 is greater than 0.010 (sorted according to the magnitude of the difference, DIFF)

SPECIES	VARIETY	LOCATION	TISSUE	NO.	N. DET	MEAN	DIFF
Herring	Pacific	Pacific NWest	whole	20	19	.260	-0.242
Sole	Petrale	Pacific NWest	muscle	11	6	.347	-0.187
Tuna	Bigeye	Hawaii	liver	2	1	.250	-0.123
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	6	5	.130	-0.104
Cod	Atlantic	N. Atlantic	liver	2	1	.210	-0.103
Crab	Tanner (Bairdi)	Alaska	meat	10	5	.208	-0.102
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	7	5	.140	-0.096
Shrimp	Alaska (Sidestriped)	Alaska	tail, peeled	7	4	.168	-0.093
Cod	Atlantic	N. Atlantic	liver	6	5	.110	-0.088
Shrimp	Ocean	Pacific NWest	tail, peeled	10	6	.136	-0.079
Cod	Atlantic	N. Atlantic	liver	4	2	.158	-0.077
Clam	Butter	Pacific NWest	shucked, large	10	8	.100	-0.076
Mullet	Striped	Hawaii	muscle	18	16	.090	-0.076
Salmon	Coho (Silver)	Alaska	muscle	10	7	.110	-0.074
Crab	Tanner (Bairdi)	Alaska	meat	10	5	.152	-0.074
Mullet	Striped	South Atlantic	muscle	19	15	.098	-0.073
Oyster	Pacific (Giant)	California	shucked	10	8	.090	-0.068
Scallop	Calico	S. Atlantic	abductor muscle	10	8	.090	-0.068
Clam	Hard	N. Atlantic	shucked, cherrysto	10	5	.141	-0.068
Squid	Shortfinned	N. Atlantic	mantle, skinless	4	2	.135	-0.065
Shrimp	Brown	Gulf	tail, peeled	10	8	.085	-0.064
Oyster	Pacific (Giant)	California	shucked	20	12	.111	-0.064
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	20	13	.100	-0.062
Squid	Shortfinned	N. Atlantic	mantle, skinless	2	1	.120	-0.058
Tuna	Yellowfin	Hawaii	liver	2	1	.120	-0.058
Clam	Razor	Alaska	shucked	11	8	.083	-0.057
Croaker	Atlantic	Gulf	muscle	9	6	.090	-0.057
Pollock	Walleye (Alaska)	Alaska	muscle	28	12	.135	-0.056
Squid	Shortfinned	N. Atlantic	mantle, skinless	11	6	.105	-0.055
Shrimp	Pink	Gulf	tail, peeled	20	10	.114	-0.055
Salmon	Coho (Silver)	Pacific NWest	liver	2	1	.110	-0.053
Mackerel	Jack	California	headed	4	3	.070	-0.049
Trout (Sea)	Silver (White)	Gulf	muscle	10	5	.100	-0.048
Clam	Soft	N. Atlantic	shucked	19	11	.086	-0.047
Flounder	Fourspot	N. Atlantic	muscle	3	1	.145	-0.047
Mullet	Striped	Gulf	muscle	12	10	.060	-0.046
Shrimp	White	Gulf	tail, peeled	10	8	.060	-0.044
Squid	Shortfinned	N. Atlantic	mantle, skinless	5	4	.060	-0.044
Cod	Atlantic	N. Atlantic	muscle	16	6	.121	-0.044
Pollock		N. Atlantic	liver	3	2	.070	-0.043
Flounder	Winter	North Atlantic	muscle	10	4	.113	-0.043

Mackerel	King	Gulf	ROE	9	2	.199	-0.043
Flounder	Witch	N. Atlantic	muscle	2	1	.090	-0.043
Tuna	Skipjack	Pacific	liver	2	1	.090	-0.043
Herring	Atlantic	North Atlantic	whole	12	11	.050	-0.041
Scallop	Calico	S. Atlantic	shucked	10	6	.073	-0.041
Squid	Shortfinned	N. Atlantic	mantle, skinless	10	6	.073	-0.041
Mullet	Striped	South Atlantic	muscle	10	9	.050	-0.041
Shrimp	Pink (Northern)	Alaska	tail, peeled	10	9	.050	-0.041
Flounder	Winter	North Atlantic	muscle	2	1	.085	-0.040
Squid	Pacific	California	whole	29	19	.064	-0.039
Oyster	Eastern	S. Atlantic	shucked	10	3	.133	-0.038
Flounder	Winter	North Atlantic	muscle	5	2	.100	-0.038
Salmon	Sockeye (Red)	Pacific NWest	muscle	12	7	.068	-0.037
Abalone	Red	California	shucked	10	5	.078	-0.037
Oyster	Eastern	N. Atlantic	shucked, std.	10	7	.057	-0.036
Crab	Tanner (Bairdi)	Alaska	meat	10	3	.126	-0.036
Herring	Round	North Atlantic	H & G tailless	10	6	.065	-0.036
Flounder	Southern	S. Atlantic	muscle	10	4	.095	-0.036
Pollock		N. Atlantic	liver	7	5	.055	-0.036
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	7	3	.088	-0.036
Scallop	Calico	S. Atlantic	abductor muscle	10	5	.076	-0.036
Flounder	Summer (Fluke)	S. Atlantic	muscle	20	6	.119	-0.034
Trout (Sea)	Sand	Gulf	muscle	5	3	.060	-0.033
Crab	Rock	N. Atlantic	meat	5	1	.169	-0.033
Mullet	Striped	Gulf	muscle	15	14	.040	-0.033
Flounder	Winter	North Atlantic	muscle	4	2	.070	-0.033
Scup		North Atlantic	muscle	2	1	.070	-0.033
Salmon	Chum (Keta)	Alaska	muscle	10	4	.086	-0.032
Shrimp	Pink (Northern)	Alaska	tail, peeled	9	5	.063	-0.032
Mullet	Striped	South Atlantic	muscle	4	1	.133	-0.032
Squid	Shortfinned	N. Atlantic	mantle, skinless	14	8	.060	-0.031
Clam	Surf	N. Atlantic	shucked, whole	19	9	.070	-0.031
Pollock	Walleye (Alaska)	Alaska	liver	3	2	.050	-0.030
Anchovy	Northern	California	whole	10	4	.080	-0.030
Scallop	Sea (smooth)	N. Atlantic	abductor muscle	10	7	.047	-0.029
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	10	4	.078	-0.029
Herring	Atlantic	North Atlantic	headed	6	5	.040	-0.029
Herring	Atlantic	North Atlantic	whole	29	14	.065	-0.029
Shrimp	Brown	Gulf	tail, peeled	10	4	.077	-0.029
Salmon	Chinock (King)	Pacific NWest	liver	5	1	.149	-0.029
Snapper	Red (EMU)	Hawaii	muscle	18	1	.522	-0.029
Flounder	Witch	N. Atlantic	muscle	16	3	.156	-0.028
Flounder	Yellowtail	North Atlantic	muscle	10	3	.099	-0.028
Mackerel	Atlantic	North Atlantic	muscle	8	5	.050	-0.028
Oyster	Eastern	N. Atlantic	shucked, select	10	8	.040	-0.028
Shrimp	White	Gulf	tail, peeled	10	8	.040	-0.028
Mullet	Striped	Hawaii	muscle	9	6	.047	-0.028

Shrimp	Pink	Gulf	tail, peeled	9	2	.130	-0.028
Pollock		N. Atlantic	liver	14	8	.053	-0.027
Shrimp	Pink (Northern)	N. Atlantic	tail, peeled	11	7	.048	-0.027
Shark	Blue	North Atlantic	liver	9	2	.127	-0.027
Scup		North Atlantic	muscle	6	2	.086	-0.027
Flounder	Winter	North Atlantic	muscle	10	4	.072	-0.027
Flounder	Yellowtail	North Atlantic	muscle	3	2	.045	-0.027
Salmon	Chinock (King)	Alaska	muscle	10	8	.038	-0.026
Mackerel	Spanish	South Atlantic	muscle	20	3	.181	-0.026
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	4	3	.040	-0.026
Squid	Shortfinned	N. Atlantic	mantle, skinless	4	3	.040	-0.026
Flounder	Gulf	Gulf	muscle	19	5	.101	-0.025
Trout (Sea)	Gray (Weakfish)	N. Atlantic	whole	10	4	.068	-0.025
Octopus	Marmuratus	Hawaii	mantle, skinless	36	17	.058	-0.025
Flounder	Fourspot	N. Atlantic	muscle	4	2	.055	-0.025
Herring	Atlantic	North Atlantic	whole	3	1	.080	-0.025
Croaker	Atlantic	N. Atlantic	muscle	5	1	.130	-0.025
Perch	Ocean (Pacific)	Pacific NWest	muscle	10	7	.040	-0.025
Shrimp	Alaska (Sidestriped)	Alaska	tail, peeled	10	7	.040	-0.025
Oyster	Pacific (Giant)	Pacific NWest	shucked, medium	9	4	.060	-0.024
Flounder	Winter	North Atlantic	muscle	7	4	.047	-0.024
Flounder	Witch	N. Atlantic	muscle	5	2	.065	-0.024
Flounder	Winter	North Atlantic	muscle	15	9	.045	-0.024
Salmon	Chum (Keta)	Alaska	muscle	9	4	.059	-0.024
Sole	Dover	Pacific NWest	muscle	10	3	.085	-0.024
Flounder	Winter	North Atlantic	muscle	6	1	.147	-0.024
Bass	striped	N. Atlantic	muscle	16	8	.052	-0.024
Cod	Atlantic	N. Atlantic	liver	3	2	.040	-0.023
Halibut	Pacific	Pacific NWest	liver	3	2	.040	-0.023
Mackerel	Atlantic	North Atlantic	muscle	11	4	.069	-0.023
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	13	7	.048	-0.023
Mullet	Striped	South Atlantic	muscle	2	1	.050	-0.023
Herring	Atlantic	North Atlantic	muscle	10	9	.030	-0.023
Mullet	Silver (white)	South Atlantic	muscle	24	18	.035	-0.023
Oyster	Pacific (Giant)	Pacific NWest	shucked, small	10	5	.050	-0.023
Shrimp	Pink	Gulf	tail, peeled	9	8	.030	-0.022
Herring	Round	North Atlantic	H & G tailless	27	21	.033	-0.022
Bass	striped	Pacific NWest	muscle	40	1	.858	-0.021
Flounder	Witch	N. Atlantic	muscle	15	3	.111	-0.021
Mullet	Striped	Gulf	muscle	20	11	.043	-0.021
Cod	Atlantic	N. Atlantic	liver	5	2	.057	-0.021
Flounder	Witch	N. Atlantic	muscle	4	1	.088	-0.021
Clam	Razor	Pacific NWest	shucked	10	5	.046	-0.021
Flounder	Winter	North Atlantic	muscle	21	6	.076	-0.020
Herring	Atlantic	North Atlantic	muscle	12	8	.035	-0.020
Scup		North Atlantic	muscle	5	1	.105	-0.020
Sole	Petrale	Pacific NWest	muscle	2	1	.045	-0.020

Shark	Blacktip	South Atlantic	liver	3	1	.065	-0.020
Squid	Pacific	California	whole	10	6	.038	-0.020
Squid	Atl. Longfinned	N. Atlantic	mantle, skinless	17	7	.053	-0.020
Mackerel	Atlantic	North Atlantic	muscle	36	17	.046	-0.019
Oyster	Eastern	N. Atlantic	shucked	20	9	.048	-0.019
Trout	Rainbow/Steelhead	Pacific NWest	muscle	6	2	.063	-0.019
Trout (Sea)	Silver (White)	Gulf	muscle	10	3	.069	-0.019
Shrimp	Brown	Gulf	tail, peeled	17	3	.113	-0.019
Scup		North Atlantic	muscle	6	3	.043	-0.019
Croaker	Atlantic	S. Atlantic	muscle	12	4	.061	-0.019
Clam	Razor	Pacific NWest	shucked	10	5	.042	-0.019
Shrimp	White	S. Atlantic	tail, peeled	10	2	.096	-0.018
Shrimp	Pink (Northern)	N. Atlantic	tail, peeled	10	4	.050	-0.018
Salmon	Chum (Keta)	Pacific NWest	muscle	7	5	.030	-0.018
Squid	Atl. Longfinned	N. Atlantic	whole	23	9	.050	-0.018
Flounder	Witch	N. Atlantic	muscle	10	2	.093	-0.018
Scallop	Atlantic Bay	S. Atlantic	abductor muscle	10	6	.034	-0.017
Flounder	Fourspot	N. Atlantic	muscle	6	1	.109	-0.017
Anchovy	Northern	California	whole	10	4	.048	-0.017
Scallop	Atlantic Bay	S. Atlantic	abductor muscle	10	2	.091	-0.017
Halibut	Pacific	Pacific NWest	muscle	10	3	.062	-0.017
Salmon	Sockeye (Red)	Alaska	muscle	19	9	.041	-0.017
Croaker	Atlantic	N. Atlantic	muscle	10	6	.033	-0.017
Cod	Pacific (Gray)	Alaska	liver	5	2	.047	-0.017
Trout (Sea)	Silver (White)	Gulf	muscle	13	2	.114	-0.017
Shrimp	Pink (Northern)	N. Atlantic	tail, peeled	3	1	.055	-0.017
Anchovy	Northern	California	whole	10	8	.025	-0.016
Crab	Blue	N. Atlantic	claw & body meat	10	5	.037	-0.016
Mackerel	Atlantic	North Atlantic	muscle	7	4	.033	-0.016
Squid	Shortfinned	N. Atlantic	mantle, skinless	20	5	.069	-0.016
Flounder	Southern	Gulf	muscle	4	1	.067	-0.016
Flounder	Fourspot	N. Atlantic	muscle	19	3	.103	-0.015
Flounder	Winter	North Atlantic	muscle	12	4	.051	-0.015
Bass	striped	California	muscle	28	1	.432	-0.015
Salmon	Pink	Alaska	muscle	9	4	.039	-0.015
Clam	Razor	Alaska	shucked	8	4	.035	-0.015
Croaker	Atlantic	Gulf	muscle	2	1	.035	-0.015
Halibut	Pacific	Pacific NWest	liver	8	6	.025	-0.015
Clam	Hard	N. Atlantic	shucked, mixed	20	5	.065	-0.015
Oyster	Eastern	Gulf	shucked	11	5	.038	-0.015
Squid	Shortfinned	N. Atlantic	mantle, skinless	5	3	.030	-0.015
Tuna	Yellowfin	Hawaii	muscle	10	3	.054	-0.015
Flounder	Fourspot	N. Atlantic	muscle	6	1	.093	-0.015
Shrimp	Pink	Gulf	tail, peeled	10	5	.034	-0.015
Clam	Hard	N. Atlantic	shucked, littleneck	16	7	.038	-0.014
Abalone	Green	California	shucked	10	6	.029	-0.014
Herring	Round	North Atlantic	H & G tailless	7	5	.025	-0.014

Shrimp	Pink (Northern)	N. Atlantic	tail, peeled	9	4	.037	-0.014
Herring	Atlantic	North Atlantic	whole	17	16	.020	-0.014
Shrimp	White	Gulf	tail, peeled	17	3	.085	-0.014
Shrimp	Brown	Gulf	tail, peeled	13	7	.031	-0.014
Clam	Hard	N. Atlantic	shucked, cherrysto	30	13	.037	-0.014
Mullet	Striped	Hawaii	muscle	13	12	.020	-0.014
Oyster	Eastern	Gulf	shucked	20	12	.028	-0.014
Oyster	Pacific (Giant)	Pacific NWest	shucked, medium	10	6	.028	-0.014
Scup		North Atlantic	muscle	11	10	.020	-0.014
Oyster	Eastern	N. Atlantic	shucked, select	16	9	.029	-0.014
Anchovy	Northern	California	whole	10	9	.020	-0.014
Croaker	Atlantic	Gulf	muscle	10	9	.020	-0.014
Salmon	Sockeye (Red)	Alaska	muscle	10	9	.020	-0.014
Oyster	Pacific (Giant)	Pacific NWest	shucked	10	4	.038	-0.013
Clam	Hard	N. Atlantic	shucked, chowder	49	14	.050	-0.013
Croaker	Atlantic	S. Atlantic	muscle	2	1	.030	-0.013
Haddock		N. Atlantic	liver	2	1	.030	-0.013
Oyster	Eastern	S.Atlantic	shucked	10	5	.030	-0.013
Perch	Ocean (Pacific)	Pacific NWest	liver	8	4	.030	-0.013
Snapper	Vermilion	South Atlantic	muscle	2	1	.030	-0.013
Lobster	Atlantic Spiny	Gulf	tail meat	12	3	.055	-0.013
Tuna	Skipjack	Pacific	muscle	20	3	.088	-0.012
Clam	Butter	Pacific NWest	shucked, ex. large	9	4	.033	-0.012
Salmon	Chinock (King)	Alaska	muscle	9	3	.042	-0.012
Flounder	Windowpane	N. Atlantic	muscle	7	1	.090	-0.012
Salmon	Chinock (King)	Alaska	muscle	10	8	.020	-0.012
Scallop	Pink	Alaska	abductor muscle	5	4	.020	-0.012
Scup		North Atlantic	muscle	5	3	.025	-0.012
Squid	Shortfinned	N. Atlantic	mantle, skinless	5	4	.020	-0.012
Haddock		N. Atlantic	muscle	5	1	.065	-0.012
Squid	Shortfinned	N. Atlantic	mantle, skinless	9	1	.112	-0.012
Shrimp	Brown	Gulf	tail, peeled	3	1	.040	-0.012
Flounder	Witch	N. Atlantic	muscle	15	2	.092	-0.012
Salmon	Coho (Silver)	Pacific NWest	muscle	10	5	.028	-0.012
Flounder	Fourspot	N. Atlantic	muscle	18	2	.108	-0.011
Clam	Butter	Pacific NWest	shucked	4	3	.020	-0.011
Shrimp	Pink (Northern)	N. Atlantic	tail, peeled	4	1	.050	-0.011
Salmon	Sockeye (Red)	Alaska	muscle	10	4	.033	-0.011
Perch	Ocean (Redfish)	North Atlantic	muscle	14	1	.161	-0.011
Haddock		N. Atlantic	muscle	9	1	.105	-0.011
Crab	King	Alaska	meat	9	3	.038	-0.011
Salmon	Pink	Alaska	muscle	10	6	.023	-0.011

APPENDIX D

HUMAN FISH CONSUMPTION AND MERCURY INGESTION DISTRIBUTIONS

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D.1 Introduction

This Appendix presents an analysis of the third National Health and Nutrition Examination Survey (NHANES III) data on frequency of fish and shellfish consumption over an one-month interval, 24-hour recall data for consumption of fish and shellfish, body weight (in kilograms) and mean mercury concentrations in fish and shellfish. These data were utilized to estimate national exposure distributions for ingestion of mercury from fish and shellfish for a time period defined as one month or 30 days. Mathematical distributions were fit to data addressing the number and size of fish meals and associated mercury ingestion for several ethnic and racial groups within the general U.S. population. Analyses for higher-frequency fish consumers, women of child-bearing age and children were also performed.

D.2 Methods and Assumptions

All variables in this analysis were assumed to be lognormally distributed and independent. Parameters of the lognormal distributions are expressed as the geometric mean (GM) and the geometric standard deviation (GSD). The geometric mean (and median) is defined as e^{μ}, where μ is the mean of the logarithms of the observations. The geometric standard deviation is defined as e^{σ}, where σ is the standard deviation of the logarithms of the observations.

The data available for estimation of distribution parameters were in the form of cumulative distribution percentiles and moments (arithmetic mean and standard deviation). The primary approach to fitting lognormal distributions to the data was by the method of moments, in which the sample mean and sample standard deviation, themselves, are used as estimates of the parameters. For the lognormal, the parameters are determined in log space (mean and standard deviation of the logs of the observations). In this analysis, the GM and GSD were estimated from the arithmetic mean and standard deviation using analytic formulas relating the arithmetic and geometric moments (Evans et al., 1993). In some cases the arithmetic moments did not provide reasonable estimates of the geometric moments. In these cases parameter estimation focused on the range between the 50th (median) and 95th percentiles. μ was assumed to be the log of the median. σ was estimated as the average of the difference of the logs of the 75th, 90th and 95th percentiles and μ, divided by the corresponding z-score from the standard unit normal distribution. Distributions derived by the percentile method should be considered to be less reliable than by the method of moments. The fit of the distributions to the data in this range was assessed by graphical analysis and percentile matching.

D.3 Population Exposure Equations

Daily mercury ingestion from fish consumption is given as Equation 1.

$$Hg_{DAILY} = \frac{Hg_{MEAL} \ x \ Nmeals}{30} \qquad \textbf{(1)}$$

where

Hg_{DAILY}	is daily ingestion of total mercury (µg/kg*bw*-day),
Hg_{MEAL}	is the ingestion of total mercury per fish meal (µg/kg*bw*-meal),
Nmeals	is the number of fish meals per month ($month^{-1}$) and
30	is the number of days per month (days/month).

Daily fish consumption is given as Equation 2.

$$FC_{DAILY} = \frac{Fish_{MEAL} \ x \ Nmeals}{30} \qquad \textbf{(2)}$$

where

FC_{DAILY}	is daily *per capita* fish consumption (g/day),
$Fish_{MEAL}$	is fish consumption per fish meal (g/meal),
Nmeals	is the number of fish meals per month ($month^{-1}$) and
30	is the number of days per month (days/month).

Equations 1 and 2 are solved using analytic methods for multiplying lognormal distributions (Aitchison and Brown, 1966; see also Appendix D to Volume 3 of this Report).

D.4 Input Distributions

This section presents the development of each of the input distributions for Equations 1 and 2. The basis for each distribution is given. Moments and percentiles for all empirical distributions were based on population weighted frequencies. That is, the sample observation frequencies were projected to the national population weighted by sex and age frequencies in the national population (NHANES III).

D.4.1 Mercury Ingestion per Fish Meal (Hg_{MEAL})

Hg_{MEAL} distributions were based on 24-hour fish (and shellfish) consumption recall data for consumers, only (per user), reported in NHANES III and average mercury concentrations reported for each fish species consumed. Consumption-mass-weighted mercury concentrations for individual species were summed across all species consumed by each survey respondent (consumers only) and divided by the respondent's body weight. Simplifying assumption were made that all the mercury was methylmercury (MeHg) and was ingested in a single meal. Empirical Hg_{MEAL} distributions were constructed for six subpopulations: the Caucasian (nonHispanic) general population ("White"), the African-American (nonHispanic) general population ("Black"), the Mexican-American general population ("Hispanic"), a more frequent fish-consuming population that included Asians, Pacific Islanders, Native Americans and Caribbean Islanders ("Other"), 15 to 44 year-old females across all groups ("Women") and 3 to 6 year-old children across all groups ("Children"). Women of this age group were selected as the MeHg Reference Dose (RfD) based primarily on effects in offspring of women exposed to MeHg during pregnancy. This particular age group of children was selected because of its much higher mercury exposure rate than other child age groups. The Hg_{MEAL} empirical distributions and lognormal approximations for each of these subpopulations are given in Table D-1.

Table D-1
Hg_{MEAL} Distributions for Selected Populations
(µg/kg*bw*-meal)

Distribution:	Population					
	White	**Black**	**Hispanic**	**Other**	**Women**	**Children**
Empirical						
n	1392	1278	914	265	882	415
mean	0.19	0.23	0.22	0.23	0.17	0.40
std. dev.	43.05	19.69	11.42	50.00	0.28	0.56
50th percentile	0.12*	0.15	0.15	0.12	0.10	0.28
75th percentile	0.26	0.32	0.31	0.32	0.22	0.49
90th percentile	0.50	0.57	0.58	0.61	0.39	0.77
95th percentile	0.73	0.77	0.77	0.97	0.53	1.08
Lognormal						
method	percentiles	percentiles	percentiles	percentiles	moments	moments
GM[a]	0.12	0.15	0.15	0.12	0.09	0.23
GSD[b]	3.01	2.82	2.91	3.77	3.14	2.83
75th percentile	0.25	0.31	0.30	0.30	0.19	0.47
90th percentile	0.50	0.57	0.58	0.66	0.38	0.88
95th percentile	0.74	0.83	0.85	1.07	0.58	1.29
mean	0.22	0.26	0.26	0.29	-	-
std. dev.	0.34	0.36	0.38	0.64	-	-

[a] Geometric Mean (and 50th percentile)

[b] Geometric Standard Deviation

*Rounded to 2 significant figures.

D.4.2 Fish Consumption per Fish Meal ($Fish_{MEAL}$)

$Fish_{MEAL}$ distributions were based on 24-hour fish (and shellfish) consumption recall data for consumers, only (per user), reported in NHANES III. A simplifying assumption was made that all the fish was consumed in a single meal. $Fish_{MEAL}$ distributions were constructed for the same five subpopulations as for Hg_{MEAL}. The $Fish_{MEAL}$ empirical distributions and lognormal approximations for each of these subpopulations are given in Table D-2.

Table D-2
$Fish_{MEAL}$ Distributions for Selected Populations
(g/meal)

Distribution:	Population					
	White	**Black**	**Hispanic**	**Other**	**Women**	**Children**
Empirical						
n	1394	1282	920	266	883	415
mean	109	128	108	106	103	57
std. dev.	16752	8004	4856	15277	116	55
50th percentile	65.5*	77.5	64.7	67.5	66.0	43.3
75th percentile	126	151	129	122	131	66.2
90th percentile	222	263	222	234	228	113
95th percentile	291	356	318	297	288	151
Lognormal						
method	percentiles	percentiles	percentiles	percentiles	moments	moments
Gm[a]	65.5	77.5	64.7	67.5	68.6	40.7
GSD[b]	2.57	2.60	2.67	2.50	2.47	2.26
75th percentile	124	148	125	125	126	70.6
90th percentile	220	264	228	219	219	116
95th percentile	310	373	326	305	304	156
mean	102	122	105	103	-	-
std. dev.	123	150	134	119	-	-

[a] Geometric Mean (and 50th percentile)

[b] Geometric Standard Deviation

* Rounded to 3 significant figures.

D.4.3 Number of Fish Meals per Month (Nmeals)

Nmeals distributions were based on monthly fish (and shellfish) consumption frequency data for all respondents (*per capita*) reported in NHANES III. The frequency of fish meals consumed per month was treated as a continuous variable for estimation of long-term fish consumption rates. Values at the reference percentiles (50th, 75th, 90th and 95th) were estimated by linear interpolation from cumulative discrete frequency distributions. As these data are from the general population (not just fish consumers), a significant fraction of respondents reported eating no fish in the last month (11-14%). Nmeals distributions were constructed for the same subpopulations as for Hg_{MEAL} and $Fish_{MEAL}$ except for "Women" and "Children," for which data were not available. An Nmeals distribution for the general population across all other groups ("All") was used as a surrogate for "Women" and "Children." Nmeals empirical distributions and lognormal approximations for each of these subpopulations are given in Table D-3.

Table D-3
Nmeals Distributions for Selected Populations
($month^{-1}$)

Distribution	Population: White	Black	Hispanic	Other	All
Empirical					
n	7410	5594	5394	785	19,200
mean	5.6	6.5	4.7	8.3	5.8
std. dev.	6.2	8.2	5.8	2.6	6.9
50th percentile	3.4*	3.8	2.9	4.1	3.5
75th percentile	7.2	8.0	5.8	9.9	7.4
90th percentile	12	13	11	22	12
95th percentile	16	18	14	31	17
99th percentile	30	31	28	43	30
maximum	150	220	150	61	220
Lognormal					
method	moments	moments	moments	moments	moments
GM[a]	3.7	4.0	3.0	5.3	3.8
GSD[b]	2.5	2.7	2.6	2.6	2.5
75th percentile	6.8	7.8	5.7	10	7.1
90th percentile	12	14	10	18	12
95th percentile	16	20	14	25	18
99th percentile	30	39	28	19	33

[a] Geometric Mean (and 50th percentile)

[b] Geometric Standard Deviation

* Rounded to 2 significant figures.

D.5 Simulation Output

The results of the solution of Equation 1 (Hg_{DAILY}) are given for adults and children in Tables D-4 and D-5, respectively. The percentile at which the MeHg RfD falls in the Hg_{DAILY} output is given for adults (Table D-4). Direct comparison to the RfD is most appropriate for women of child-bearing age, as the MeHg RfD is based, primarily, on effects in the offspring of exposures to their mothers during pregnancy (see Volume V of this report; also U. S. EPA, 1997). That is, although the effects were observed in children, the exposure (and it's associated metric) was to the mother. The RfD is designed to be protective of all sensitive subpopulations. In this case (MeHg), the developing fetus was judged to be the most sensitive population. An uncertainty factor was included in the RfD to account for the lack of data on post-natal development, among other factors.

The results of the solution of Equation 2 (FC_{DAILY}) are given for adults and children in Tables D-6 and D-7, respectively. The percentile at which fish ingestion exceeds 100 g/day in the $Fish_{DAILY}$ output is also shown.

Table D-4
Hg_{DAILY} Distributions for Selected Populations: Adults
(µg/kg*bw*-day)

Percentile	Population				
	White[a]	**Black[b]**	**Hispanic[c]**	**Other[d]**	**Women[e]**
50th	0.015	0.020	0.015	0.021	0.011
75th	0.039	0.053	0.047	0.064	0.030
90th	0.092	0.13	0.11	0.17	0.074
95th	0.15	0.21	0.18	0.31	0.13
RfD Percentile	91.0	86.8	91.0	82.7	93.2

[a] GM = 0.0149, GSD = 4.145
[b] GM = 0.0204, GSD = 4.153
[c] GM = 0.0145, GSD = 4.216
[d] GM = 0.0214, GSD = 5.123
[d] GM = 0.0111, GSD = 4.382

Table D-5
Hg_{DAILY} Distributions for Selected Populations: Children
(μg/kg*bw*-day)

Percentile	Ethnicity				
	All Groups[a]	**White**[b]	**Black**[c]	**Hispanic**[d]	**Other**[e]
50th	0.029	0.029	0.031	0.023	0.041
75th	0.075	0.072	0.082	0.060	0.11
90th	0.18	0.17	0.19	0.14	0.25
95th	0.29	0.28	0.33	0.24	0.42

[a] GM = 0.0292, GSD = 4.050
[b] GM = 0.0286, GSD = 3.961
[c] GM = 0.0311, GSD = 4.173
[d] GM = 0.0230, GSD = 4.130
[e] GM = 0.0411, GSD = 4.102
Nmeals distributions from general population for each group (not child-specific)
Hg_{MEAL} distribution from 3-6 year-old children across ethnicities (not group-specific)

Table D-6
FC_{DAILY} Distributions for Selected Populations: Adults
(g/day)

Percentile	Population				
	White[a]	**Black**[b]	**Hispanic**[c]	**Other**[c]	**Women**[d]
50th	8.1	10	6.4	12	8.6
75th	19	26	16	29	21
90th	43	60	37	65	46
95th	69	99	62	105	73
100 g percentile	97.3	95.1	97.7	94.6	97.0

[a] GM = 8.08, GSD = 3.685
[b] GM = 10.4, GSD = 3.925
[c] GM = 6.43, GSD = 3.957
[c] GM = 11.9, GSD = 3.751
[d] GM = 8.63, GSD = 3.668

Table D-7
FC_{DAILY} Distributions for Selected Populations: Children
(g/day)

Percentile	Ethnicity				
	All Groups[a]	White[b]	Black[c]	Hispanic[d]	Other[e]
50th	5.1	5.0	5.5	4.0	7.2
75th	12	11	13	9.5	17
90th	25	24	28	20	36
95th	39	37	44	32	57
100 g percentile	>99	>99	99	>99	98

[a] GM = 5.12, GSD = 3.456
[b] GM = 5.01, GSD = 3.370
[c] GM = 5.46, GSD = 3.573
[d] GM = 4.04, GSD = 3.532
[e] GM = 7.18, GSD = 3.506
Nmeals distributions from general population for each group (not child-specific)
$Fish_{MEAL}$ distribution from 3-6 year-old children across ethnicities (not group-specific)

D.6 Sensitivity Analysis

D.6.1 Adequacy of Input Distribution Fit

A general trend for fitting input distributions by the percentile method was for higher estimates of σ at lower percentiles but with fairly good agreement in the targeted range (75th to 95th percentiles); coefficients of variation for σ estimates for a given data set were in the range of 0.03 to 0.1. Distributions fit by this method were not particularly good approximations of the data outside these percentile ranges. The impact of overestimating the lower end of the input distributions on the output of Equations 1 and 2 is discussed in the next section.

Quantile-quantile plots (QQ plots) are shown for each of the distributions in Figures D-1, D-2 and D-3, which show the Hg_{MEAL}, $Fish_{MEAL}$, and Nmeals distributions, respectively. These figures plot the z-scores of the logs of the observations against the z-scores for the corresponding fitted lognormal distribution (normal in log space). The z-scores are the number of standard deviations above or below the median. A z-score of 2 corresponds to about the 95th percentile (z= -2 ≡ 5th percentile). The 99th and 99.9th percentiles correspond to z-scores of 2.33 and 3.1, respectively. As these plots compare the logs of the distributions, zeroes in the raw data are not included. Zeroes were included, however, in the fitting process for those variables fit by the method of moments. For those distributions fit by the percentile method, the data points (50th, 75th, 90th and 95th percentiles) used in the fitting process are indicated by filled symbols on the Figures.

The solid straight lines on the QQ plots represent perfect fits. That is, a perfect fit would result in all the points lining up along the line. The direction of deviations from the line can be used to assess the direction of the prediction error. If the points curve below the line at either end, the fitted distribution will under predict actual values at that end. Conversely, if the points curve above the line, the fitted distribution will over predict. The tendency to over predict the lower tail can be seen for all of the variables. This tendency is quite marked for a number of variables, particularly for the ones fitted by the percentile method. The upper tails of the empirical distributions are all fairly well represented by the fitted distributions, even for extreme values. Nmeals/Other is an exception, but the poor fit is well beyond the 99th percentile; the data points above the 99th percentile are single observations. The effect of over prediction in the lower tail on the analytic solutions of Equations 1 and 2 will be to greatly exaggerate the lower percentiles. There will also be a tendency to over predict the upper percentiles, but probably not by a large amount. Deviations from the fit line at z-scores of less than -3 should have no effect on the output. In general, the magnitude of the over prediction is difficult to assess from the QQ plots, but will be considerably less than that resulting from over prediction in the upper tails of the input distributions. The best predictions should be for both outputs for "Women" and "Children," given the better combined fit for Hg_{MEAL}, $Fish_{MEAL}$, and Nmeals for these two groups.

Figure D-1
Quantile-Quantile Plots for Hg_{MEAL} Distributions

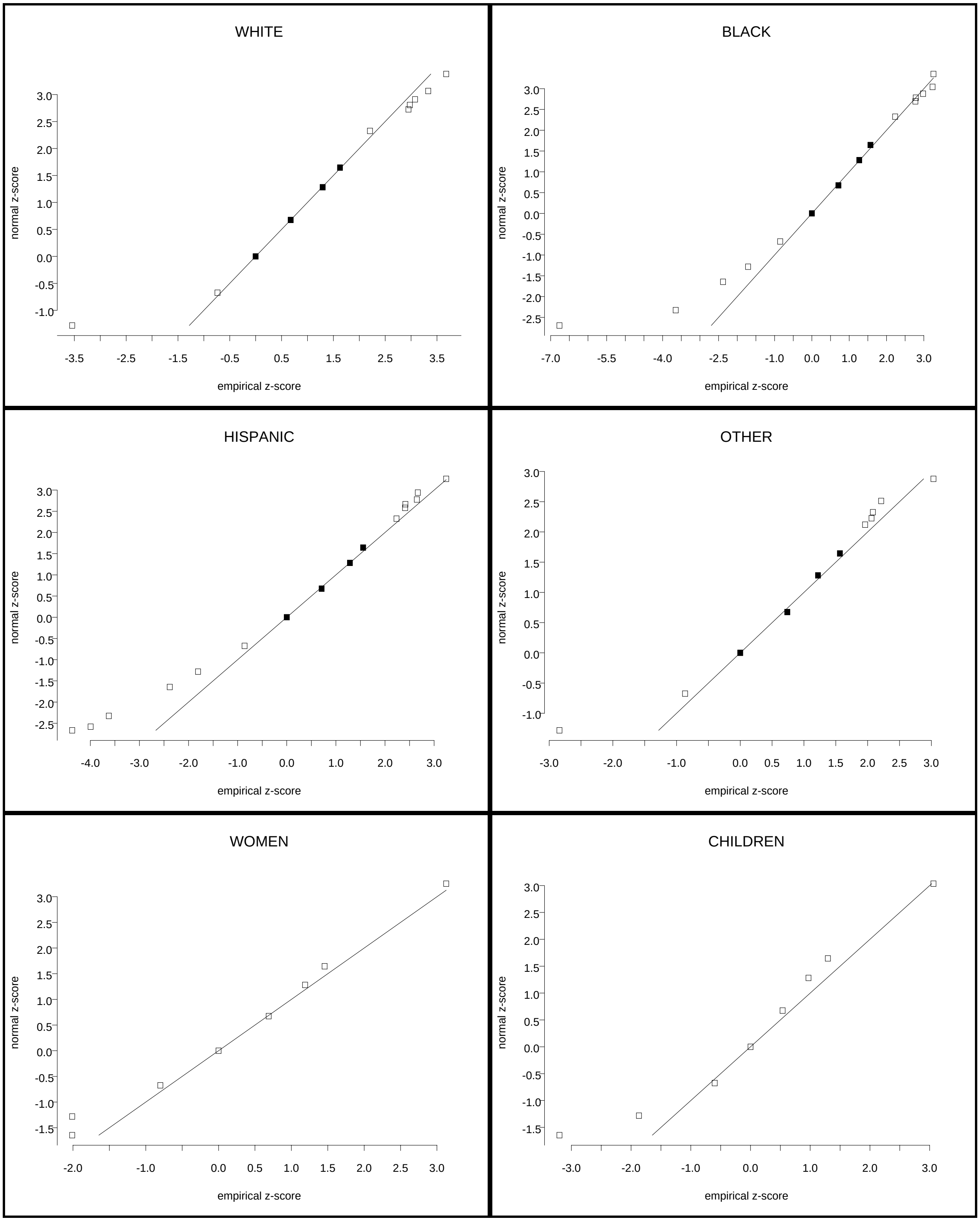


Figure D-2
Quantile-Quantile Plots for $Fish_{MEAL}$ Distributions

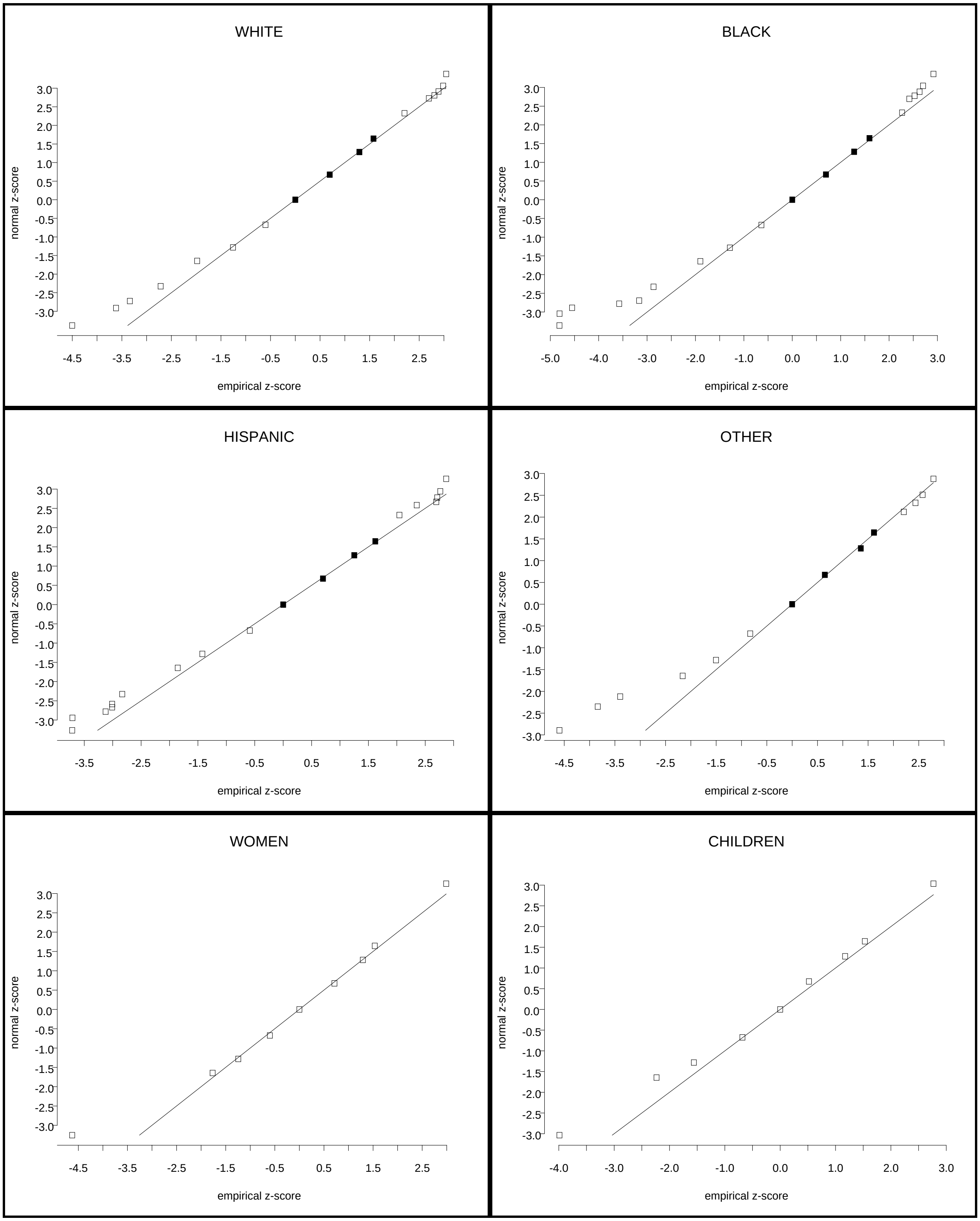
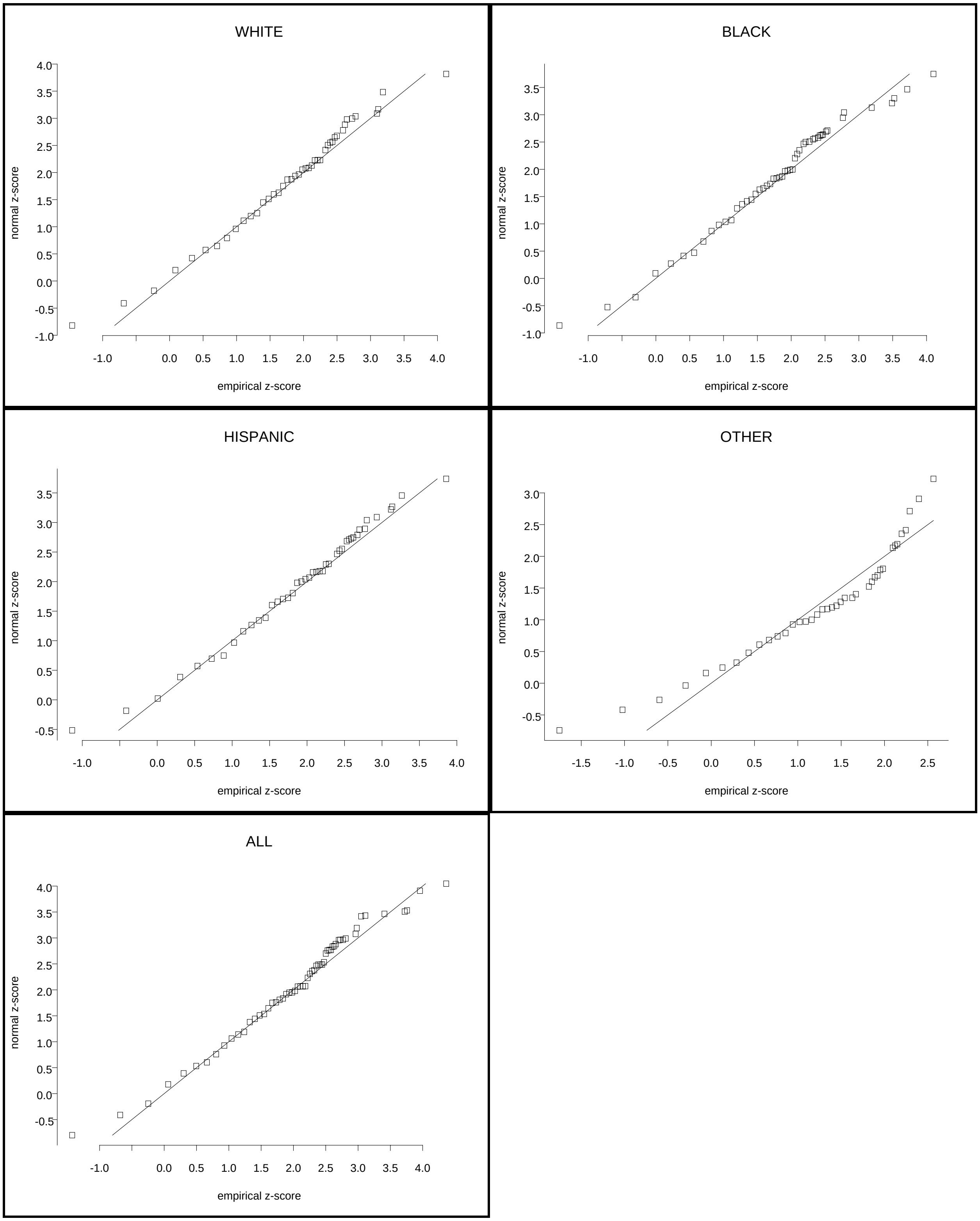


Figure D-3
Quantile-Quantile Plots for Nmeals Distributions



D.6.2 Impact of Assumptions on Simulation Output

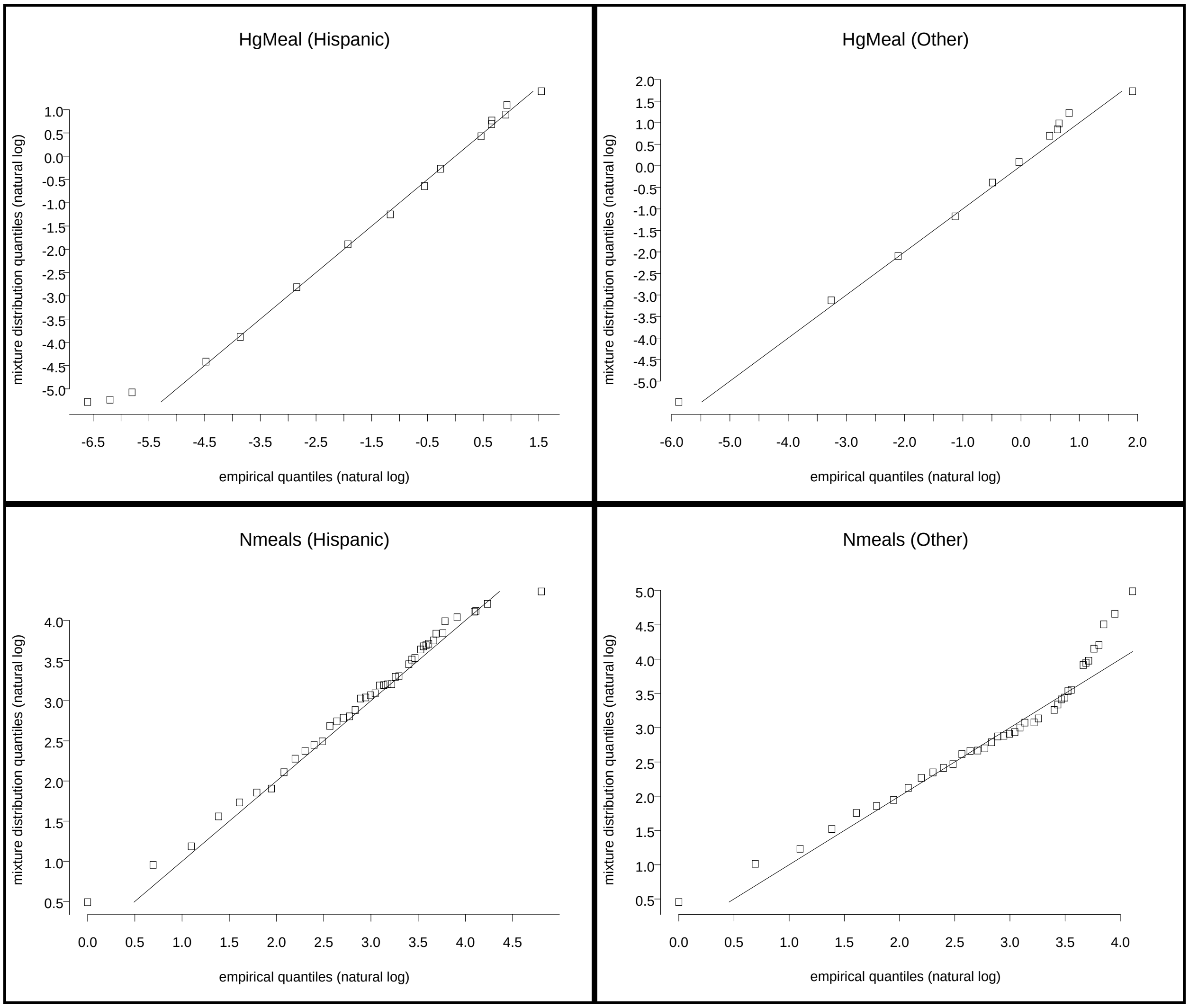
The assumption that the 24-hour recall data represent one fish meal is obviously false for all respondents who reported more than 30 fish meals per month. The assumption will result in overestimation of both Hg_{DAILY} and FC_{DAILY} at higher percentiles. The 30 fish meal per month mark falls at the 99th percentile or higher for all groups except "Other," for which the 95th percentile is 31.4 fish meals per month. The bias in Hg_{DAILY} and FC_{DAILY} for groups other than "Other" should not be significant at the 95th percentile and lower, but this assumption was not tested. The results for "Other" above the 90th percentile should be considered to be conservative.

Correlation of input variables was not considered in this analysis. Data for "Women" suggest that there is a slight positive correlation between Nmeals and the other two variables, with a more noticeable difference in $Fish_{MEAL}$ for those respondents reporting zero or one fish meal in the last month. That is, those individuals who had a low frequency of fish consumption also tended to eat less fish per meal (70 g/meal vs 108 g/meal for respondents reporting two or more fish meals per month). The result of this correlation would be an over prediction of FC_{DAILY}. The magnitude of the over prediction could not be estimated without the specific body weight of the individuals, but was judged to be small. The correlation of Nmeals and Hg_{MEAL} was very weak and was not expected to have any impact on the output. The effect of correlations on simulation output is generally smaller than that arising from the form of the assigned distribution (Bukowski et al., 1995).

The impact of the simplifying lognormal assumptions on the output of Equations 1 and 2 was investigated by defining the input distributions as mixtures (mixtures approach) and then solving the equations by Monte Carlo analysis. That is, separate distributions were fit to discrete segments of the empirical data rather than assuming a single mathematical form for the entire distribution. For several data sets where the number of zeroes was high, the proportion of zeroes was modeled as a delta function (spike), with a lognormal distribution fit to the nonzero data (delta method). For one data set with no zeroes, a log-triangular distribution was fit to the proportion of the data set that did not appear to be lognormal (the lower 25%) and a lognormal was fit to the remainder (two-distribution method). In each case, a composite mixtures distribution was constructed by Monte Carlo simulation.

Figure D-4 shows the QQ-plots for the mixtures distribution fits to selected variables. Two of the worst-fitting Hg_{MEAL} data sets (Hispanic and Other) were selected for this part of the analysis. The corresponding Nmeals data sets were also analyzed so that output distributions (Equation 1) could be generated. Hg_{MEAL}/Hispanic, was fit by the two-distribution method and the rest by the delta method. Distribution quantiles, in natural log units, are shown in these plots instead of z-scores, as the fitted distributions are not entirely lognormal. Otherwise, the visual fit of the distributions can be compared directly with the corresponding QQ-plots in Figures D-1 and D-3. The mixtures approach provided a better overall fit for Hg_{MEAL}, particularly at the lower end, the lower three points for Hg_{MEAL}/Hispanic being an exception. These data points, however, represent less than 1% of the distribution and would have no effect on the output. Upper percentile estimates for the mixtures approach are similar to those estimated by the simple lognormal assumptions. The Nmeals distributions estimated by the mixtures approach showed only slightly better fit (or none at all) in the lower percentiles at the expense of a slightly poorer fit at the upper extreme. Fits to Nmeals/White and Nmeals/All were similar to Nmeals/Hispanic. Overall, the mixtures approach did not improve the fit to Nmeals.

Figure D-4
Quantile-Quantile Plots for Mixtures-Distribution Fits



Results of the Monte Carlo simulations of Equation 1 using the mixtures distributions are given in Table D-8. The output was simulated with mixtures distributions for both inputs (Hg_{MEAL} and Nmeals) and for Hg_{MEAL}, only, as the mixtures approach did not provide a better fit for Nmeals. The results in Table D-8 show little effect from the simple lognormal assumption for the inputs in this limited comparison. Further analysis using the full data sets and other parametric fitting or nonparametric methods would be useful for resolving the remaining distribution fit issues.

Table D-8
Comparison of Hg_{DAILY} Output for Alternate Fits
(µg/kg*bw*-day)

Group	Hispanic			Other		
method of distribution fit	**simple lognormal**[a]	**Hg_{MEAL} mixture**[b]	**both mixtures**[c]	**simple lognormal**[a]	**Hg_{MEAL} mixture**[b]	**both mixtures**[c]
Percentiles						
50th	0.015*	0.014	0.019	0.021	0.021	0.020
75th	0.038	0.038	0.047	0.064	0.066	0.071
90th	0.092	0.086	0.11	0.17	0.18	0.20
95th	0.15	0.14	0.18	0.31	0.33	0.36
99th	0.41	0.40	0.45	0.96	0.98	1.1

[a] from Table D-4

[b] mixture for Hg_{MEAL}, only; lognormal Nmeals from Table D-3

[c] mixtures for both inputs

* Rounded to 2 significant figures.

D.6.2 Other Sources of Uncertainty

Sources of uncertainty or bias that have not been considered in this analysis include fish mercury concentrations, mercury speciation in fish and shellfish, and population weights. The mercury concentrations in the fish and shellfish were average concentrations for the identified fish species. Data were available on the distribution of mercury in each species but were not considered for this analysis. These data would provide bounds on the percentile values estimated in this analysis but would not change the median estimates for each percentile. The mercury in all "fish" species was assumed to be methylmercury, which is a fairly sound assumption for finfish (Bloom, 1992), but somewhat less so for shellfish and other species. The impact of this assumption on the simulation output was not investigated but was assumed to be small. The uncertainty in the population weighting protocol in NHANES III was not investigated either.

D.7 Conclusions

The derived distributions are thought to be more characteristic of month-long patterns of fish and shellfish consumption than are either of the two individual distributions that formed the input variables. The resulting derived distribution was done to maximize fit between the 75th and 95th percentiles.

D.8 References

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