Summary of Human Health Risks from Methylmercury Consumption

(by Hillary Carpenter and Patricia McCann, Minnesota Department of Health)
Summary of Human Health Risks from Methylmercury Consumption

As outlined in the original Mercury Contamination Reduction Initiative Advisory Council’s Report, mercury released to the atmosphere is problematic for human health because it can be converted to methylmercury, which can then accumulate in fish that are subsequently consumed by humans.

Several well-documented human exposure episodes have proven beyond a doubt that mercury is a very effective neurotoxin. Mercury has dose-related effects that range from an alteration in the ability of nerves to conduct impulses to changes in the way nerve cells divide and differentiate. This makes mercury particularly dangerous to the developing nervous systems of fetuses and young children. It also means that the impacts of mercury can range from the subtle, such as altered cognitive and motor function that can only be observed with sophisticated testing techniques, to cerebral palsy, profound mental retardation, and even death.

As with all toxic materials there is a question of dose — what type of exposure to methylmercury is needed before damage will be apparent. The U.S. Environmental Protection Agency (EPA) established a reference dose (RfD) of 0.1 microgram (µg) of methylmercury per kilogram (kg) per day for pregnant women and young children based on the neurological effects that were seen following an accidental exposure that occurred in Iraq. Shortcomings in the Iraq data set resulted in controversy regarding the adequacy of this approach. Adding to the controversy was the fact that two large-scale epidemiological studies examining the low dose effects of methylmercury were nearing completion. These factors led the U.S. Congress to direct the EPA to contract with the National Academy of Science’s National Research Council (NRC) to evaluate the available data and assess the adequacy of the EPA’s RfD for methylmercury.

The NRC’s report evaluated the results of several epidemiologic studies and reinforced previous conclusions that small amounts of mercury have the ability to cause subtle neurological damage to human fetuses. The report also outlined evidence that suggested that, in addition to its neurotoxicity, methylmercury can have adverse impacts on both the developing and adult cardiovascular systems (blood-pressure regulation, heart-rate variability, and heart disease) and that the adverse cardiovascular effects may occur at or below methylmercury exposures that cause neurotoxicity. The NRC report supported the EPA’s RfD of 0.1 µg/kg/day for methylmercury but suggested that the RfD be based on results from the Faroe Islands or New Zealand studies rather than on the Iraq data set. The EPA subsequently developed a RfD for methylmercury that was based on modeling done with data from the Faroe Island study.

Adding to the concerns regarding the safety of eating fish containing methylmercury are the results from a recently released CDC-NHANES report that indicated that 10 percent of their sample of women between 16 and 49 years of age had been exposed to levels of methylmercury that are close to those which have observable adverse effects. Using this information and the number of births registered in the United States in 1998, the EPA has estimated that as many as 400,000 newborns each year are at risk of elevated
methylmercury exposure. Methylmercury exposure levels estimated in the recent North Dakota EERC Fish Consumption Survey Project support those reported by CDC’s NHANES.

There is obviously a concern about exposure of infants and children to mercury. A report recently released by the American Academy of Pediatrics included the following statement: “the developing fetus and young children are thought to be disproportionately affected by mercury exposure, because many aspects of development, particularly brain maturation, can be disturbed by the presence of mercury. Minimizing mercury exposure is, therefore, essential to optimal child health.” The Minnesota Department of Health (MDH) continues to provide advice on eating fish based on mercury levels in fish. In 2001, the MDH began providing advice for all lakes and rivers based on mercury levels measured in fish throughout the state.

There are benefits associated with eating fish. Fish is an excellent low-fat source of protein. The optimal situation would be a reduction in the levels of mercury in fish tissue that would lead to a relaxation or elimination of the need for fish consumption advisories. Until this goal is reached, the MDH will continue to provide the public with information that allows the consumer to limit exposure to mercury by selecting fish that have the lowest concentrations of mercury.

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1 This summary was provided by Hillary Carpenter, toxicologist, and Patricia McCann, research scientist, Minnesota Department of Health, St. Paul.


3 A reference dose is defined as an estimate (with an uncertainty spanning perhaps an order of magnitude) of daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime.

4 Toxicological Effects of Methylmercury, 2000, National Research Council, National Academy Press, Washington, D.C.


6 EERC report.

Executive Summary from

*Toxicological Effects of Methylmercury*

(National Research Council, 2000)

**EXECUTIVE SUMMARY**

**Mercury** (Hg) is widespread and persistent in the environment. Its use in many products and its emission from combustion processes have resulted in well-documented instances of population poisonings, high-level exposures of occupational groups, and worldwide chronic, low-level environmental exposures. In the environment, Hg is found in its elemental form and in various organic compounds and complexes. Methylmercury (MeHg), one organic form of Hg, can accumulate up the food chain in aquatic systems and lead to high concentrations of MeHg in predatory fish,¹ which, when consumed by humans, can result in an increased risk of adverse effects in highly exposed or sensitive populations. Consumption of contaminated fish is the major source of human exposure to MeHg in the United States.

In recent years, the U.S. Environmental Protection Agency (EPA) has issued two major reports on Hg to the U.S. Congress on Hg—the Mercury Study Report to Congress (issued in December 1997) and the Utility Hazardous Air Pollutant Report to Congress (issued in March 1998). In those reports, fossil-fuel power plants, especially coal-fired utility boilers, were identified as the source category that generates the greatest Hg emissions, releasing approximately 40 tons annually in the United States. EPA is currently considering rule-making for supplemental controls on Hg emissions from utilities. However, because of gaps in the

¹In this report, the term fish includes shellfish and marine mammals, such as pilot whales, that are consumed by certain populations.
scientific data regarding Hg toxicity, Congress directed EPA, in the appropriations report for EPA's fiscal 1999 funding, to request the National Academy of Sciences to perform an independent study on the toxicological effects of MeHg and to prepare recommendations on the establishment of a scientifically appropriate MeHg exposure reference dose (RfD).²

THE CHARGE TO THE COMMITTEE

In response to the request, the National Research Council (NRC) of the National Academies of Sciences and Engineering convened the Committee on Toxicological Effects of Methylmercury, whose members have expertise in the fields of toxicology, pharmacology, medicine, epidemiology, neurophysiology, developmental psychology, public health, nutrition, statistics, exposure assessment, and risk assessment. Specifically, the committee was assigned the following tasks:

1. Evaluate the body of evidence that led to EPA's current RfD for MeHg. On the basis of available human epidemiological and animal toxicity data, determine whether the critical study, end point of toxicity, and uncertainty factors used by EPA in the derivation of the RfD for MeHg are scientifically appropriate. Sensitive subpopulations should be considered.

2. Evaluate any new data not considered in the 1997 Mercury Study Report to Congress that could affect the adequacy of EPA's MeHg RfD for protecting human health.

3. Consider exposures in the environment relevant to evaluation of likely human exposures (especially to sensitive subpopulations and especially from consumption of fish that contain MeHg). The evaluation should focus on those elements of exposure relevant to the establishment of an appropriate RfD.

4. Identify data gaps and make recommendations for future research.

²A reference dose is defined as an estimate of a daily exposure to the human population (including sensitive subpopulations) that is likely to be without a risk of adverse effects when experienced over a lifetime.
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THE COMMITTEE’S APPROACH TO ITS CHARGE

To gather background information relevant to MeHg toxicity, the committee heard presentations from various government agencies, trade organizations, public interest groups, and concerned citizens. Representatives from the offices of Congressman Alan Mollohan (West Virginia) and Senator Patrick Leahy (Vermont) also addressed the committee.

The committee evaluated the body of evidence that provided the scientific basis for the risk assessments conducted by EPA and other regulatory and health agencies. The committee also evaluated new findings that have emerged since the development of EPA’s current RfD and met with the investigators of major ongoing epidemiological studies to examine and compare the methods and results.

The committee was not charged to calculate an RfD for MeHg. Instead, in its report, the committee provides scientific guidance to EPA on the development of an RfD. To develop such guidance, the committee reviewed the health effects of MeHg to determine the target organ, critical study, end point of toxicity, and dose on which to base the RfD. Because various biomarkers of exposure (i.e., concentrations of Hg in hair and umbilical-cord blood) have been used to estimate the dose of MeHg ingested by individuals, the committee evaluated the appropriateness of those biomarkers for estimating dose and the extent to which individual differences can influence the estimates. Other sources of uncertainty in the MeHg data base that should be considered when deriving an RfD were also evaluated. To estimate the appropriate point of departure\(^3\) to use in calculating an RfD, the committee statistically analyzed available dose-response data. A margin-of-exposure\(^4\) analysis was also performed to assess the public-health implications of MeHg.

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\(^3\)The point of departure represents an estimate or observed level of exposure or dose which is associated with an increase in adverse effect(s) in the study population. Examples of points of departure include NOAELs, LOAELs, BMDs, and BMDLs.

\(^4\)A margin-of-exposure analysis compares the levels of MeHg to which the U.S. population is exposed with the point of departure to characterize the risk to the U.S. population. The larger the ratio, the greater degree of assumed safety for the population.
THE COMMITTEE'S EVALUATION

Health Effects of Methylmercury

MeHg is rapidly absorbed from the gastrointestinal tract and readily enters the adult and fetal brain, where it accumulates and is slowly converted to inorganic Hg. The exact mechanism by which MeHg causes neurotoxic effects is not known, and data are not available on how exposure to other forms of Hg affects MeHg toxicity.

MeHg is highly toxic. Exposure to MeHg can result in adverse effects in several organ systems throughout the life span of humans and animals. There are extensive data on the effects of MeHg on the development of the brain (neurodevelopmental effects) in humans and animals. The most severe effects reported in humans were seen following high-dose poisoning episodes in Japan and Iraq. Effects included mental retardation, cerebral palsy, deafness, blindness, and dysarthria in individuals who were exposed in utero and sensory and motor impairment in exposed adults. Chronic, low-dose prenatal MeHg exposure from maternal consumption of fish has been associated with more subtle end points of neurotoxicity in children. Those end points include poor performance on neurobehavioral tests, particularly on tests of attention, fine-motor function, language, visual-spatial abilities (e.g., drawing), and verbal memory. Of three large epidemiological studies, two studies—one conducted in the Faroe Islands and one in New Zealand—found such associations, but those effects were not seen in a major study conducted in the Seychelles islands.

Overall, data from animal studies, including studies on nonhuman primates, indicate that the developing nervous system is a sensitive target organ for low-dose MeHg exposure. Results from animal studies have reported effects on cognitive, motor, and sensory functions.

There is also evidence in humans and animals that exposure to MeHg can have adverse effects on the developing and adult cardiovascular system (blood-pressure regulation, heart-rate variability, and heart disease). Some research demonstrated adverse cardiovascular effects at or below MeHg exposure levels associated with neurodevelopmental effects. Some studies demonstrated an association between MeHg and cancer, but, overall, the evidence for MeHg being carcinogenic is incon-
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Inclusive. There is also evidence in animals that the immune and reproductive systems are sensitive targets for MeHg.

On the basis of the body of evidence from human and animal studies, the committee concludes that neurodevelopmental deficits are the most sensitive, well-documented effects and currently the most appropriate for the derivation of the RfD.

Determination of the Critical Study for the RfD

The standard approach for developing an RfD involves selecting a critical study that is well conducted and identifies the most sensitive endpoint of toxicity. The current EPA RfD is based on data from a poisoning episode in Iraq. However, MeHg exposures in that study population were not comparable to low-level, chronic exposures seen in the North American population, and there are a number of uncertainties associated with the Iraqi data. In light of those considerations and more recent epidemiological studies, the committee concludes that the Iraqi study should no longer be considered the critical study for the derivation of the RfD.

Results from the three large epidemiological studies—the Seychelles, Faroe Islands, and New Zealand studies—have added substantially to the body of knowledge on brain development following long-term exposure to small amounts of MeHg. Each of the studies was well designed and carefully conducted, and each examined prenatal MeHg exposures within the range of the general U.S. population exposures. In the Faroe Islands and New Zealand studies, MeHg exposure was associated with poor neurodevelopmental outcomes, but no relation with outcome was seen in the Seychelles study.

Differences in the study designs and in the characteristics of the study populations might explain the differences in findings between the Faroe and the Seychelles studies. Differences include the ways MeHg exposure was measured (i.e., in umbilical-cord blood versus maternal hair), the types of neurological and psychological tests administered, the age of testing (7 years versus 5.5 years of age), and the patterns of MeHg exposure. When taking the New Zealand study into account, however, those differences in study characteristics do not appear to explain the
differences in the findings. The New Zealand study used a research
design and entailed a pattern of exposure similar to the Seychelles study,
but it reported associations with Hg that were similar to those found in
the Faroe Islands.

The committee concludes that there do not appear to be any serious
flaws in the design and conduct of the Seychelles, Faroe Islands, and
New Zealand studies that would preclude their use in a risk assessment.
However, because there is a large body of scientific evidence showing
adverse neurodevelopmental effects, including well-designed epidemi-
ological studies, the committee concludes that an RfD should not be
derived from a study, such as the Seychelles study, that did not observe
any associations with MeHg.

In comparing the studies that observed effects, the strengths of the
New Zealand study include an ethnically mixed population and the use
of end points that are more valid for predicting school performance. The
advantages of the Faroe Islands study over the New Zealand study
include a larger study population, the use of two measures of exposure
(i.e., hair and umbilical-cord blood), extensive peer review in the epide-
miological literature, and re-analysis in response to questions raised by
panelists at a 1998 NIEHS workshop and by this committee in the course
of its deliberations.

The Faroe Islands population was also exposed to relatively high
levels of polychlorinated biphenyls (PCBs). However, on the basis of an
analysis of the data, the committee concluded that the adverse effects
found in the Faroe Islands study, including those seen in the Boston
Naming Test,\(^5\) were not attributable to PCB exposure and that PCB
exposure did not invalidate the use of the Faroe Islands study as the
basis of risk assessment for MeHg.

The committee concludes that, given the strengths of the Faroe Islands
study, it is the most appropriate study for deriving an RfD.

**Estimation of Dose and Biological Variability**

In epidemiological studies, uncertainties and limitations in estimating

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\(^5\)The Boston Naming Test is a neuropsychological test that assesses an
individual's ability to retrieve a word that appropriately expresses a particular
concept.
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Exposures can make it difficult to quantify dose-response associations and can thereby lead to inaccuracies when deriving an RfD. An individual’s exposure to MeHg can be estimated from dietary records or by measuring a biomarker of exposure (i.e., concentration of Hg in the blood or hair).

Dietary records, umbilical-cord-blood Hg concentrations, and maternal-hair Hg concentrations all provide different kinds of exposure information. Dietary records can provide information on Hg intake but depend on accurate knowledge of Hg concentrations in fish. The records also might be subject to problems with estimating portion size and capturing intermittent eating patterns. Umbilical-cord-blood Hg concentrations would be expected to correlate most closely with fetal-brain Hg concentrations during late gestation and correlate less well with Hg intake than do the other measures (e.g., dietary records and maternal-hair Hg concentration). Maternal-hair Hg concentrations can provide data on Hg exposure over time, but they might not provide as close a correlation with fetal-brain Hg concentrations as umbilical-cord-blood Hg concentrations, at least during the latter period of gestation. Use of data from two or more of these measurement methods increases the likelihood of uncovering true dose-response relationships. The use of either umbilical-cord-blood or maternal-hair Hg concentrations as biomarkers of exposure is adequate for estimating a dose received by an individual.

Individual responses to MeHg exposure are variable and a key source of uncertainty. Factors that might influence the responses include genetics, age, sex, health status, nutritional supplements, nutritional influences, including dietary interactions, and linking the time and intensity of MeHg exposure to the critical periods of brain development. In addition, people exposed to the same amount of MeHg can have different concentrations of Hg at the target organ because of individual variability in the way the body handles MeHg. Individual differences that affect the estimation of dose can be addressed in the derivation of the RfD by applying an uncertainty factor to the estimated dose. If an RfD is based on a Hg concentration in maternal-hair or umbilical-cord blood, adjusting by an uncertainty factor of 2-3 would account for individual differences in the estimation of dose in 95% to 99% of the general population.
Modeling the Dose-Response Relationships

An important step in deriving an RfD is choosing an appropriate dose to be used as the "point of departure" (i.e., the dose to which uncertainty factors will be applied to estimate the RfD). The best available data for assessing the risk of adverse effects for MeHg are from the Faroe Islands study. Because those data are epidemiological, and exposure is measured on a continuous scale, there is no generally accepted procedure for determining a dose at which no adverse effects occur. The committee concludes, therefore, that a statistical approach (i.e., calculation of a benchmark dose level, BMDL) should be used to determine the point of departure for MeHg instead of identifying the dose at which no adverse effects occur or the lowest dose at which adverse effects occur. The committee cautions, however, that the type of statistical analysis conducted (i.e., the model choice — K power, logarithmic, or square root) can have a substantial effect on the estimated BMDL. The committee recommends the use of the K-power model with the constraint of K ≥ 1, because it is the most plausible model from a biological perspective and also because it tends to yield the most consistent results for the Faroe Islands data. It should be noted that, for the data from the Faroe Islands study, the results of the K-power model with the constraint of K ≥ 1 are equivalent to the results of the linear model.

The adverse effects observed in the Faroe Islands study were most sensitively detected when using cord blood as the biomarker. Based on cord-blood analyses from the Faroe Islands study, the lowest BMD for a neurobehavioral end point the committee considered to be sufficiently reliable is for the Boston Naming Test. Thus, on the basis of that study and that test, the committee's preferred estimate of the BMDL is 58 parts per billion (ppb) of Hg in cord blood. To estimate this BMDL, the

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6 A benchmark dose level is the lowest dose, estimated from the modeled data, that is expected to be associated with a small increase in the incidence of adverse outcome (typically in the range of 1% to 10%).

7 The BMDL of 58 ppb is calculated statistically and represents the lower 95% confidence limit on the dose (or biomarker concentration) that is estimated to result in a 5% increase in the incidence of abnormal scores on the Boston Naming Test.
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The committee’s calculations involved a series of steps, each involving one or more assumptions and related uncertainties. Alternative assumptions could have an impact on the estimated BMDL value. In selecting a single point of departure, the committee followed established public health practice of using the lowest value for the most sensitive, relevant end point.

In addition to deriving a BMDL based on the Faroe Islands study, the committee performed an integrative analysis of the data from all three studies to evaluate the full range of effects of MeHg exposure. The values obtained by the committee using that approach are consistent with the results of the benchmark analysis of the Boston Naming Test from the Faroe Islands study. Because an integrative analysis is not a standard approach at present, the committee does not recommend that it be used as the basis for an RfD.

**Public-Health Implications**

The committee’s margin-of-exposure analysis based on estimates of MeHg exposures in U.S. populations indicates that the risk of adverse effects from current MeHg exposures in the majority of the population is low. However, individuals with high MeHg exposures from frequent fish consumption might have little or no margin of safety (i.e., exposures of high-end consumers are close to those with observable adverse effects). The population at highest risk is the children of women who consumed large amounts of fish and seafood during pregnancy. The committee concludes that the risk to that population is likely to be sufficient to result in an increase in the number of children who have to struggle to keep up in school and who might require remedial classes or special education. Because of the beneficial effects of fish consumption, the long-term goal needs to be a reduction in the concentrations of MeHg in fish rather than a replacement of fish in the diet by other foods. In the interim, the best method of maintaining fish consumption and minimizing Hg exposure is the consumption of fish known to have lower MeHg concentrations.

In the derivation of an RfD, the benchmark dose is divided by uncertainty factors. The committee identified two major categories of uncertainty, based on the body of scientific literature, that should be consid-
ered when revising the RfD: (1) biological variability when estimating dose and (2) data-base insufficiencies. On the basis of the available scientific data, the committee concludes that a safety factor of 2-3 will account for biological variability in dose estimation. The choice of an uncertainty factor for data-base insufficiencies is, in part, a policy decision. However, given the data indicating possible long-term neurological effects not evident at childhood, immunotoxicity, and cardiovascular effects, the committee supports an overall composite uncertainty factor of no less than 10.

RESEARCH NEEDS

To better characterize the health effects of MeHg, the committee recommends further investigation of the following:

- The impacts of MeHg on the prevalence of hypertension and cardiovascular disease in the United States. Such data should be considered in a re-evaluation of the RfD as they become available.
- The relationships between low-dose exposure to MeHg throughout the life span of humans and animals and carcinogenic, reproductive, neurological, and immunological effects.
- The potential for delayed neurological effects resulting from Hg remaining in the brain years after exposure.
- The emergence of neurological effects later in life following low-dose prenatal MeHg exposure.
- The mechanisms underlying MeHg toxicity.

To improve estimates of dose and to clarify the impact of biological variability and other factors on MeHg dose-response relationships, the committee recommends the following:

- The analysis of hair samples to evaluate the variability in short-term exposures, including peak exposures. Hair that has been stored from the Seychelles and the Faroe Islands studies should be analyzed to determine variability in exposures over time.
- The collection of information on what species of fish are eaten at
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specific meals to improve estimates of dietary intakes and temporal variability in MeHg intake.

- The assessment of factors that can influence individual responses to MeHg exposures in humans and animals. Such factors include age, sex, genetics, health status, nutritional supplement use, and diet. Food components considered to be protective against MeHg toxicity in humans also deserve closer study (e.g., wheat bran and vitamin E).

To determine the most appropriate methods for handling model uncertainty in benchmark analysis, the committee recommends that further statistical research be conducted.

To better characterize the risk to the U.S. population from current MeHg exposures, the committee recommends obtaining data on the following:

- Regional differences in MeHg exposure, populations with high consumptions of fish, and trends in MeHg exposure. Characterization should include improved nutritional and dietary exposure assessments and improved biomonitoring of subpopulations.
- Exposure to all chemical forms of Hg, including exposure to elemental Hg from dental amalgams.

RECOMMENDATIONS

On the basis of its evaluation, the committee’s consensus is that the value of EPA’s current RfD for MeHg, 0.1 μg/kg per day, is a scientifically justifiable level for the protection of public health. However, the committee recommends that the Iraqi study no longer be used as the scientific basis of the RfD. The RfD should still be based on the developmental neurotoxic effects of MeHg, but the Faroe Islands study should be used as the critical study for the derivation of the RfD. Based on cord-blood analyses from the Faroe Islands study, the lowest BMD for a neurobehavioral end point the committee considered to be sufficiently reliable is for the Boston Naming Test. For that end point, dose-response data based on Hg concentrations in cord blood should be modeled using
the K-power model (K \geq 1). That approach estimates a BMDL of 58 ppb of Hg in cord blood (corresponding to a BMDL of 12 ppm of Hg in hair) as a reasonable point of departure for deriving the RfD. To calculate the RfD, the BMDL should be divided by uncertainty factors that take into consideration biological variability when estimating dose and MeHg data-base insufficiencies. As stated earlier, given those considerations, an uncertainty factor of at least 10 is supported by the committee.

The committee further concludes that the case of MeHg presents a strong illustration of the need for harmonization of efforts to establish a common scientific basis for exposure guidance and to reduce current differences among agencies, recognizing that risk-management efforts reflect the differing mandates and responsibilities of the agencies.
“Blood and Hair Mercury Levels in Young Children and Women of Childbearing Age — United States, 1999”

(from March 2, 2001 Morbidity and Mortality Weekly Report)
Blood and Hair Mercury Levels in Young Children and Women of Childbearing Age -- United States, 1999

Mercury (Hg), a heavy metal, is widespread and persistent in the environment. Exposure to hazardous Hg levels can cause permanent neurologic and kidney impairment (1-3). Elemental or inorganic Hg released into the air or water becomes methylated in the environment where it accumulates in animal tissues and increases in concentration through the food chain. The U.S. population primarily is exposed to methylmercury by eating fish. Methylmercury exposures to women of childbearing age are of great concern because a fetus is highly susceptible to adverse effects. This report presents preliminary estimates of blood and hair Hg levels from the 1999 National Health and Nutrition Examination Survey (NHANES 1999) and compares them with a recent toxicologic review by the National Research Council (NRC). The findings suggest that Hg levels in young children and women of childbearing age generally are below those considered hazardous. These preliminary estimates show that approximately 10% of women have Hg levels within one-tenth of potentially hazardous levels indicating a narrow margin of safety for some women and supporting efforts to reduce methylmercury exposure.

CDC’s NHANES is a continuous survey of the health and nutritional status of the U.S. civilian, noninstitutionalized population with each year of data constituting a representative population sample. A household interview and a physical examination were conducted for each survey participant. During the physical examination, blood was collected by venipuncture for all persons aged >1 year and hair samples, consisting of approximately 100 strands, were cut from the occipital position of the head of children aged 1-5 years and women aged 16-49 years. Whole blood specimens were analyzed for total Hg and inorganic Hg for children aged 1-5 years and women aged 16-49 years by automated cold vapor atomic absorption spectrophotometry in CDC’s trace elements laboratory. The detection limit was 0.2 parts per billion (ppb) for total Hg and 0.4 ppb for inorganic Hg (4). Hairs of 0.6 inches (1.5 cm) closest to the scalp (approximately 1 month’s growth) were analyzed for total Hg concentration using cold vapor atomic fluorescence spectroscopy (5). The limit of detection for total Hg in hair varied by analytic batch; the maximum limit of detection (0.1 parts per million [ppm]) was used in these analyses. Blood Hg levels less than the limit of detection were assigned a value equal to the detection limit divided by the square root of two for calculation of geometric mean values.

The geometric mean total blood Hg concentration for all women aged 16-49 years and children aged 1-5 years was 1.2 ppb and 0.3 ppb, respectively; the 90th percentile of blood Hg for women and children was 6.2 ppb and 1.4 ppb, respectively (Table 1).
Almost all inorganic Hg levels were undetectable; therefore, these measures indicate blood methylmercury levels. The 90th percentile of hair Hg for women and children was 1.4 ppm and 0.4 ppm, respectively. Geometric mean values were not calculated for hair Hg values.


Editorial Note:
The NHANES1999 blood and hair Hg data are the first nationally representative human tissue measures of the U.S. population’s exposure to Hg. Previous estimates of methylmercury exposure in the general population were based on exposure models using fish tissue Hg concentrations and dietary recall survey data (1). The NRC review provided guidance to the Environmental Protection Agency (EPA) for developing an exposure reference dose for methylmercury (i.e., an estimated daily exposure that probably is free of risk for adverse effects over the course of a person’s life) (3). The NRC report recommended statistical modeling of results from an epidemiologic study conducted in the Faroe Islands near Iceland, where methylmercury exposures are high because of the large amount of seafood eaten by the local population. Results of this study were used to calculate a benchmark dose (BMD), an estimate of a methylmercury exposure in utero associated with an increase in the prevalence of abnormal scores on cognitive function tests in children. The lower 95% confidence limit of the BMD (BMDL*) was recommended to calculate the EPA reference dose. The NRC committee recommended a BMDL of 58 ppb Hg in cord blood (corresponding to 12 ppm Hg in maternal hair) (3). In the HANES 1999 sample, there were no measurements of blood values >58 ppb or hair values >12 ppm. A margin-of-exposure analysis (i.e., an evaluation of the ratio of BMDL to estimated population exposure levels) showed ratios of <10 when comparing BMDL with NHANES 1999 estimates of the 90th percentile for blood and hair Hg levels in women of childbearing age. Margin-of-exposure measures of this magnitude indicate a narrow margin of safety (3) and suggest that efforts aimed at decreasing human exposure to methylmercury should continue.

The findings in this study are subject to at least three limitations. First, the ratio of Hg in cord and maternal blood is uncertain. The NRC committee summarized some studies that suggest that cord blood values may be 20%-30% higher than corresponding maternal blood levels. However, other studies suggest that the ratio is closer to 1:1 (3); therefore, the NHANES values may not be directly comparable to BMDL recommended by NRC. Second, NHANES cannot provide estimates of Hg exposure in certain highly exposed groups (e.g., subsistence fishermen and others who eat large amounts of fish). Published data from studies of highly exposed U.S. populations indicated that some persons attain Hg tissue levels above BMDL (1). Third, the sample size of NHANES 1999 was small and the 1999 survey was conducted in only 12 locations. More data are needed to confirm these findings.
The long-term strategy for reducing exposure to Hg is to lower concentrations of Hg in fish by limiting Hg releases into the atmosphere from burning mercury-containing fuel and waste and from other industrial processes. On the basis of data from EPA’s National Toxics Inventory, air emissions of Hg decreased approximately 21% during 1990-1996, largely because of regulations for waste incineration (7). EPA expects this trend to continue as regulations are implemented for waste incineration and chlorine production facilities and are developed for electric power utilities (8,9). Fish is high in protein and nutrients and low in saturated fatty acids and cholesterol and should be considered an important part of the diet. The short-term strategy to reduce Hg exposure is to eat fish with low Hg levels and to avoid or to moderate intake of fish with high Hg levels. State-based fish advisories and bans identify fish species contaminated by Hg and their locations and provide safety advice (http://www.epa.gov/ost/fish†). The Food and Drug Administration advises that pregnant women and those who may become pregnant should not eat shark, swordfish, king mackerel, and tile fish known to contain elevated levels of methylmercury. Information is available at http://www.fda.gov/bbs/topics/ANSWERS/2001/advisory.html†. U.S. population estimates of Hg tissue levels by race/ethnicity, region, and fish consumption will become available after 2 additional years of NHANES data collection. NHANES will provide the opportunity to measure tissue Hg levels and to monitor the effectiveness of continuing efforts to reduce methylmercury exposure in the U.S. population.

References


*A BMD of 85 ppb Hg in cord blood or 17 ppm Hg in maternal hair was estimated to result in an increase in the proportion of abnormal scores on the Boston Naming Test for children exposed in utero from an estimated background prevalence of 5% to a prevalence of 10% (6). BMDL recommended by NRC is the lower 95% confidence bound of the BMD.

† References to sites of nonCDC organizations on the World-Wide Web are provided as a service to MMWR readers and do not constitute or imply endorsement of these organizations or their programs by CDC or the U.S. Department of Health and Human Services. CDC is not responsible for the content of pages found at these sites.

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TABLE 1. Selected percentiles and geometric means of blood and hair mercury (Hg) concentrations for children aged 1-5 years and women aged 16-49 years, National Health and Nutrition Examination Survey, United States, 1999

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<td>Children</td>
<td>248 0.3 (0.2-0.4)</td>
<td>&lt;LOD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>679 1.2 (0.9-1.6)</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1-0.3)</td>
</tr>
<tr>
<td>Hair Hg¶</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>338 —**</td>
<td>&lt;LOD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>702 —</td>
<td>&lt;LOD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Confidence interval
† Parts per billion
§ Limit of detection
¶ Parts per million
** Not calculated. Proportion <LOD too high to be valid.

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This page last reviewed 5/2/01
Summary of Results from

Fish Consumption Survey: Minnesota and North Dakota
Fish Consumption Project Public Summary 29 October 2001

Fish Consumption Survey: Minnesota and North Dakota

Summary of Results

During the fall of 2000, the Energy & Environmental Research Center (EERC) conducted a survey to determine the fish-eating habits of residents of Minnesota and North Dakota as part of a research project entitled Fish Consumption Survey: Minnesota and North Dakota. Researchers used consumption information from the survey to estimate potential mercury exposure from fish.

The health benefits of eating fish have been widely studied and accepted by the medical and scientific communities. However, all fish contain some mercury, a naturally occurring element that exists in air, water, and soil. The mercury exposure estimated from the survey results indicate that some residents of both states may be eating enough fish to be exposed to more mercury than recommended by the U.S. Environmental Protection Agency (EPA). The benefits of fish consumption outweigh the risks as long as a person’s exposure is below EPA’s recommended level. To determine if you need to make changes in your fish-eating habits, consult the fish consumption guidelines enclosed. In particular, women who are or may become pregnant and young children should follow the guidelines.

Who Responded to the Survey?

Nine hundred eighty-eight households in Minnesota and 577 households in North Dakota responded to the request for information. Their answers to questions about purchased, restaurant, sport-caught, and netted fish meals, fish consumption advisory awareness, age, gender, and weight were entered into a database. Respondents’ names are held confidential and will not be made public. Comparison of the age and race information to U.S. Census data suggests that survey respondents were of similar makeup to the white and American Indian populations for both Minnesota and North Dakota. African and Asian Americans (who make up 4.7% of the population in Minnesota and 1.1% of the population in North Dakota) were not well represented by the respondents.

Survey Results

Researchers looked at the fish consumption of all respondents as a whole (called general population) and sorted responses into the following groups: children aged 0-14, men older than 14, women aged 15 to 44, and women older than 44.

How Often Are Fish Eaten? The general population of both states eats fish at levels similar to national averages. The respondents ate fish, on average, about once every 8 days (based on a 4-ounce portion). About 5% of residents eat an average of 2 ½ ounces of fish daily or about one meal every other day.

Approximately 4% of the Minnesota respondents and 4% of the North Dakota respondents reported eating no fish. Of those who reported eating fish, some ate only
store-bought and restaurant fish, some ate only sport caught and netted fish, and others ate both. Two tables at the end of this summary show the breakdown of fish meals. Table 1 shows how often respondents reported eating fish. Table 2 shows that distribution by percentages.

Respondents were also asked how many sport-caught fish meals they ate each month of the past year. The results show that people eat the most sport-caught fish in the summer (the average was more than two meals per month in June and July) and the least meals in October and November (about one meal per two months). Seasonality is an important component in assessing whether mercury exposure levels vary during the year. Knowing the seasonal pattern of fish meals may help researchers determine whether some residents may be at risk for short-term exposure to high levels of mercury from intense consumption versus spreading consumption out over several months. The survey did not include questions about seasonal variation in purchased or restaurant fish consumption to compare with sport-caught fish consumption.

**Who’s Eating What Fish?** About two-thirds of the fish eaten come from a store or restaurant; one-third comes from fishing and netting. While the total amount of fish meals is similar to results from surveys in other parts of the United States, the level of sport-caught and netted meals was lower than in other studies. Walleye and panfish were the two sport-caught meals eaten most often. Nearly 10% of respondents reported eating walleye 1 to 3 times per month. Of the purchased fish meals, tuna was reported consumed the most, often 1 to 3 times per month. Shellfish was reported consumed at least once in the last year by 75% of respondents. Only 10% of respondents reported eating swordfish in the last year.

**Mercury Exposure: Estimated from Fish Consumption Survey Responses** One of the ways people are exposed to mercury is through eating fish. One outcome of this investigation of fish-eating tendencies was an estimate of mercury exposure. All fish have some mercury, but some species, and older, larger fish have more mercury than others. Exposure to mercury from eating fish was estimated using the fish consumption (species, size of fish and meal frequency) reported in the survey, data on mercury levels measured in fish from Minnesota and North Dakota, and mercury in marine fish data published by the U.S. EPA.

**Mercury Exposure: Estimated from Analysis of Hair** Some of the mercury a person ingests ends up in their hair. The amount of mercury in hair can be used to estimate a person’s exposure. The EERC research project analyzed hair samples from 80 respondents for mercury to see if the amount of mercury in the hair correlated with the estimated amount of mercury respondents might have been exposed to based on their reported fish consumption. None of the samples contained mercury at levels to raise health concerns. These results suggest that the women who donated hair were not exposed to an excessive amount of mercury from all sources.
Relationship of Mercury in Hair and Mercury Exposure Estimated from the Survey Responses  The estimated mercury exposures determined from the hair samples were compared to the mercury exposures estimated from the fish consumption survey responses. Statistical analysis of the data suggests that a strong correlation exists between the values from the hair-based to the survey-based calculations. That suggests that hair mercury levels will increase with increasing reported fish consumption. However, the survey-based estimated mercury exposure is much higher than the hair-based calculation. More research in this area is needed to understand why the values are not more closely matched and to determine whether surveys of fish consumption could be used with data on mercury levels in fish to estimate mercury exposure.

More Information Is Available
For more information on this research, contact Steven Benson [(701) 777-5177] or Charlene Crocker [(701) 777-5018] at the EERC. For information on fish consumption advisories, contact Patricia McCann of the Minnesota Department of Health at (651) 215-0923 or Francis Schwindt of the North Dakota Department of Health at (701) 328—5152. The fish advisories of the Departments of Health are available at Web sites: http://www.health.state.mn.us/divs/eh/fish/ and http://www.ehs.health.state.nd.us/ndhd/environ/wq/fish/fishadvisory.pdf.

Acknowledgements
The EERC would like to thank the sponsors of this research for their assistance:
Minnesota Power
Otter Tail Power Company
Minnesota Pollution Control Agency
U.S. Department of Energy

Enclosures
MN or ND DH Fish Consumption Advisory Guide
MN An Expectant Mother's Guide to Eating Minnesota Fish
TABLE 1. Respondents were separated by age and gender to examine how often residents ate all kinds of fish. For most groups, nearly two thirds of the respondents ate at least two fish meals per month.

<table>
<thead>
<tr>
<th></th>
<th>Ate no fish</th>
<th>Less than 1 meal/month</th>
<th>1 meal/month</th>
<th>2 or more meals/month</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minnesota</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children (0-14)</td>
<td>11%</td>
<td>19%</td>
<td>16%</td>
<td>54%</td>
</tr>
<tr>
<td>Women (15-44)</td>
<td>4%</td>
<td>15%</td>
<td>21%</td>
<td>60%</td>
</tr>
<tr>
<td>Women (older than 44)</td>
<td>2%</td>
<td>9%</td>
<td>16%</td>
<td>74%</td>
</tr>
<tr>
<td>Men (older than 14)</td>
<td>1%</td>
<td>8%</td>
<td>16%</td>
<td>75%</td>
</tr>
<tr>
<td>Composite</td>
<td>4%</td>
<td>12%</td>
<td>17%</td>
<td>67%</td>
</tr>
<tr>
<td><strong>North Dakota</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children (0-14)</td>
<td>8%</td>
<td>12%</td>
<td>15%</td>
<td>66%</td>
</tr>
<tr>
<td>Women (15-44)</td>
<td>5%</td>
<td>10%</td>
<td>18%</td>
<td>67%</td>
</tr>
<tr>
<td>Women (older than 44)</td>
<td>2%</td>
<td>12%</td>
<td>18%</td>
<td>68%</td>
</tr>
<tr>
<td>Men (older than 14)</td>
<td>1%</td>
<td>9%</td>
<td>17%</td>
<td>72%</td>
</tr>
<tr>
<td>Composite</td>
<td>4%</td>
<td>11%</td>
<td>17%</td>
<td>69%</td>
</tr>
</tbody>
</table>

TABLE 2. The responses of residents that ate fish were separated by where the fish came from. Less that 10% of the respondents ate only sport caught or netted fish. In all categories except for children in Minnesota, at least two thirds of the fish-eating respondents ate both purchased and sport caught fish.

<table>
<thead>
<tr>
<th></th>
<th>% Purchased Only</th>
<th>% Sport Caught/Netted Only</th>
<th>% Both</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minnesota</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children (0-14)</td>
<td>31%</td>
<td>7%</td>
<td>62%</td>
</tr>
<tr>
<td>Women (15-44)</td>
<td>26%</td>
<td>5%</td>
<td>69%</td>
</tr>
<tr>
<td>Women (older than 44)</td>
<td>19%</td>
<td>5%</td>
<td>76%</td>
</tr>
<tr>
<td>Men (older than 14)</td>
<td>17%</td>
<td>6%</td>
<td>77%</td>
</tr>
<tr>
<td>Composite</td>
<td>22%</td>
<td>6%</td>
<td>72%</td>
</tr>
<tr>
<td><strong>North Dakota</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children (0-14)</td>
<td>26%</td>
<td>5%</td>
<td>69%</td>
</tr>
<tr>
<td>Women (15-44)</td>
<td>25%</td>
<td>5%</td>
<td>70%</td>
</tr>
<tr>
<td>Women (older than 44)</td>
<td>22%</td>
<td>7%</td>
<td>72%</td>
</tr>
<tr>
<td>Men (older than 14)</td>
<td>15%</td>
<td>7%</td>
<td>79%</td>
</tr>
<tr>
<td>Composite</td>
<td>21%</td>
<td>6%</td>
<td>73%</td>
</tr>
</tbody>
</table>
Why Do Fish Contain Mercury? (To be included only in the ND mailings)
Mercury enters aquatic (natural water) systems from surface water run off, shoreline vegetation, and atmospheric deposition. That is, mercury enters the atmosphere and is deposited on soils by precipitation, taken up by plants and washed into rivers and lakes. There are many sources of the mercury in the atmosphere. Natural sources include active volcanoes, vaporization from soils, and forest fires. Some anthropogenic (human) sources of mercury in the air are waste incinerators, landfills, and power generation facilities. In homes, businesses, and schools, mercury can be found in thermometers, fluorescent lamps, watch batteries, thermostat switches, old chemistry kits, and laboratory chemicals. Small organisms ingest the mercury present in lakes and streams passing it to the larger animals that eat them. In this manner, mercury bio-accumulate through the food chain; that is, mercury is absorbed by each animal that eats smaller mercury-storing animals. When humans eat fish, they become part of this process.