Mercury

Mercury is a metal that is liquid at room temperature. There are three major forms of mercury: 1) organic mercury; 2) non-elemental forms of inorganic mercury; and 3) elemental mercury. Organic mercury, predominantly in the form of methylmercury, is found primarily in fish. Non-elemental forms of inorganic mercury are found primarily in batteries, some disinfectants, and some health products and creams. Lastly, elemental mercury is found in thermometers, fluorescent bulbs, dental amalgam fillings, switches in certain automobiles (used for convenience lighting in hoods and trunks, mostly in vehicles manufactured prior to 2003), and other sources.[1,2]

Mercury is released from its natural form in the earth's crust as a result of both human activities and natural processes. Coal-burning power plants are the largest source of mercury emissions in the United States.[3] Other sources of mercury emissions include the combustion of waste and industrial processes that use mercury.[3,4] When released into the atmosphere, either from human activities or from non-human sources, such as volcanoes, mercury can travel long distances on global air currents and can be deposited on land and water far from its original source.[4,5] In addition to these mercury emissions, there is concern that an increase in ice melts caused by a warming climate may release some past mercury emissions that have been trapped in polar ice.[6] Moreover, mercury deposited on the surface in the Arctic vaporizes each spring when the sunlight returns, causing increased concentrations in the atmosphere.[7,8]

Human exposure to elemental and inorganic mercury can occur at work, from accidental mercury releases, through the use of products containing mercury, through ritual and folk medicine uses of mercury, as well as dental restorations with mercury-silver amalgams.[4,9,10] Sources of childhood exposure to elemental and inorganic mercury in the home include the tracking of mercury into the home from the workplace by parents, mercury-containing devices in the home, and very rarely from intentionally heating mercury in the home for the purpose of extracting gold.[11] In schools, the most common sources of exposure are elemental and inorganic mercury stored in science laboratories, and mercury from broken instruments such as thermometers; less common sources are certain mercury-containing gymnasium floors manufactured between 1960 and 1980 found in some schools.[11,12] The adverse health effects of elemental and inorganic mercury exposure in childhood have not been extensively studied. However, inhaling high concentrations of elemental mercury vapor can lead to lung problems, neurobehavioral effects, mood changes, and tremors.[9] Although elemental mercury vapor emissions from dental amalgams are a major source of mercury exposure in the U.S. general population, two prospective clinical trials in children have found no evidence of adverse effects on IQ, memory, attention, or other neurological functions.[13-15]

Thimerosal is an organic mercury-containing preservative that is used in some vaccines to prevent contamination and growth of harmful bacteria in vaccine vials. The presence of thimerosal in many vaccines administered to infants led to concerns about possible effects on children's neurological development, including a hypothesis that mercury in vaccines could be

a contributing factor to the incidence of autism. The Institute of Medicine has rejected the hypothesis of a causal relationship between thimerosal-containing vaccines and autism.[16] In addition, two recent studies have concluded that prenatal and infant exposure to thimerosal-containing vaccines is not related to increased risk of autism.[17,18] Since 2001, thimerosal has not been used in routinely administered childhood vaccines, with the exception of some influenza vaccines.[19]

Methylmercury is another form of organic mercury, which may form when mercury is deposited into water systems such as oceans, rivers, lakes, and wetlands; the mercury is converted by bacteria and other microorganisms into methylmercury. Methylmercury then bioaccumulates up the aquatic food web; fish that live long and feed on other fish (i.e., predatory fish) can accumulate high levels of methylmercury. The concentration of methylmercury in the larger fish at the top of the food chain can reach levels a million times higher than in the water.[20] Consuming fish is the main way that people are exposed to methylmercury. This includes fish commercially distributed in stores and restaurants as well as those that people catch for consumption by their families and communities. Each person's exposure depends on the amount of methylmercury in the fish that they eat and how often they eat fish. These exposure levels are of particular importance for women of child-bearing age because of the potential for prenatal exposure: methylmercury easily crosses the placenta and blood-brain barrier.[15] As such, the prenatal period is considered the most sensitive period of exposure.[15]

EPA has determined that methylmercury is known to have neurotoxic and developmental effects in humans.[4] This determination was based on effects in people prenatally exposed to extremely high levels of methylmercury during accidental mercury poisoning events in Japan and Iraq. Severe adverse health effects observed in the prenatally exposed population included cerebral palsy, intellectual disability (mental retardation), deafness, and blindness.[15,21,22]

Prospective cohort studies have been conducted in island populations where frequent fish consumption leads to methylmercury exposure in pregnant women at levels much lower than in the poisoning incidents but much greater than those typically observed in the United States. These studies are designed to investigate possible associations of prenatal methylmercury exposure with more subtle adverse neurodevelopmental effects than those observed in the poisoning incidents. However, the expected beneficial impacts of prenatal fish consumption on neurodevelopment can make it more difficult to detect such outcomes. Prenatal exposure to mercury in these studies is represented by measurement of total mercury in blood or hair samples obtained from a woman during pregnancy or at delivery. Results from such studies in New Zealand and the Faroe Islands[15,23-28] suggested that increased prenatal mercury exposure due to maternal fish consumption was associated with decrements in attention, language, memory, motor speed, and visual-spatial function (like drawing) during childhood. These associations were not seen in initial results reported from a study in the Seychelles Islands.[29] Further analyses of the Seychelles study population did find associations between prenatal mercury exposure and some neurodevelopmental deficits, after researchers had accounted for the developmental benefits of fish consumption.[30-32]

More recent studies have been conducted in Massachusetts and New York City, with maternal blood mercury levels within the range of typical levels in the U.S. general population.[33-35] In Massachusetts, total mercury in blood samples collected during the second trimester of pregnancy was associated with reduced cognitive development in testing conducted at age 3 years, after adjusting for the positive effects of fish/seafood consumption during pregnancy.[34] In the New York study, total cord blood mercury was associated with decreased IQ scores in testing conducted at age 4 years, after adjusting for the positive effects of fish/seafood consumption during pregnancy.[33]

Findings of neurodevelopmental effects from early childhood methylmercury exposure are more limited than for prenatal exposure, with several studies reporting mixed findings.[25,36-39] Animal and epidemiological studies suggest that early life exposure to methylmercury (including prenatal exposures) may also affect cardiovascular,[40,41] immune,[15,42,43] and reproductive health.[15]

Although ingestion of methylmercury in fish may be harmful, other compounds naturally present in many fish (such as high quality protein and other essential nutrients) are beneficial. In particular, fish are an excellent source of omega-3 fatty acids, which are nutrients that contribute to the healthy development of infants and children.[44] Pregnant women are advised to seek dietary sources of these fatty acids, including many species of fish. However, the levels of both methylmercury and omega-3 fatty acids can vary considerably by fish species. Thus, the type of fish, as well as portion sizes and frequency of consumption, are all important considerations for health benefits of fish and the extent of methylmercury exposure.

For these reasons, EPA and the U.S. Food and Drug Administration (FDA) issued a fish consumption advisory in 2004 that advises young children and pregnant females to consume up to 12 ounces a week of lower-mercury fish and shellfish, such as shrimp, canned light tuna, salmon, pollock, and catfish, but to avoid any consumption of high-mercury-containing fish, such as shark, swordfish, tile fish, or king mackerel.[45] EPA and FDA are currently working to update the fish consumption advisory to incorporate the most current science regarding the health benefits of fish consumption and the risks from methylmercury in fish. In 2011, the Departments of Agriculture and Health and Human Services jointly released the *2010 Dietary Guidelines for Americans*, which recommended that pregnant or breastfeeding women should consume 8–12 ounces of seafood per week, but avoid consumption of the same high-mercury-containing fish identified in the EPA-FDA advisory.[46] In addition, many state health departments provide advice regarding healthy sources of fish that are lower in mercury. Web links to state advice regarding fish consumption can be found at http://www.epa.gov/waterscience/fish/states.htm (for an example, see Washington state's "Eat Fish, Choose Wisely" available at http://www.doh.wa.gov/ehp/oehas/fish/fishchart.htm). State advisories may address both store-bought fish and fish caught by individuals in local lakes, rivers, and coastal waters.

Because methylmercury exposure in pregnant women is a concern for children health, studies have measured the level of mercury in women's bodies. Mercury can be measured in blood and is often called "blood mercury." In most cases, total blood mercury is reported, and the

measurements do not distinguish methylmercury in blood from the other forms of mercury. In the United States, and in populations where most mercury exposure comes from fish consumption, the majority of total blood mercury is from methylmercury. Among women 16 to 49 years of age in the United States, levels of mercury in blood tend to be highest for Native American, Pacific Islander, Asian American, and multi-racial women.[47-49] A survey of adults in New York City found that blood mercury levels were three times higher than the national levels. Asian Americans in this study had higher blood mercury levels than other race/ethnicity groups.[50] Among women ages 16 to 49 years in the United States, blood mercury levels are higher for those who eat fish more often or in higher quantities.[51,47] Asian American populations have been identified as high consumers of seafood compared with White non-Hispanics or Black non-Hispanics.[50]

For women of all races, blood mercury levels tend to be higher in those women with higher family incomes.[48,50,52] Fish consumption rates are highest among women with relatively high family incomes, and this higher rate of fish consumption leads to increased blood mercury levels.[48,52] Concentrations of total mercury in blood among women also seem to vary with geographic region, and potentially by coastal region. Based on data from 1999–2004, blood mercury levels for women ages 16 to 49 years were higher in the Northeastern region of the United States compared with other regions.[48] Estimated mercury intake from fish consumption also follows this observed pattern. Women living in coastal regions had blood mercury levels higher than those living in noncoastal regions, and among coastal populations, the highest blood mercury levels were reported for the Atlantic and Pacific coastal regions, followed by the Gulf Coast and Great Lakes regions, respectively. Furthermore, subsistence populations (individuals who sustain a portion of their diets by catching and eating fish from local waters), or those who consume fish as a large portion of their diet because of taste preference or in the pursuit of health benefits, may have elevated blood mercury levels, depending on the source and species of fish.[4]

The indicator that follows uses the best nationally representative data currently available on blood mercury levels over time for women of child-bearing age. Indicator B3 presents median and 95th percentile blood mercury levels for women ages 16 to 49 years.

Indicator B3: Mercury in women ages 16 to 49 years: Median and 95th percentile concentrations in blood, 1999–2010

About the Indicator: Indicator B3 presents concentrations of mercury in blood of U.S. women ages 16 to 49 years. The data are from a national survey that collects blood specimens from a representative sample of the population every two years, and then measures the concentration of mercury in the blood. The indicator presents concentrations of mercury in blood over time. The focus on women of child-bearing age is based on concern for potential adverse effects in children born to women who have been exposed to mercury.

NHANES

The National Health and Nutrition Examination Survey (NHANES) provides nationally representative biomonitoring data for mercury. NHANES is designed to assess the health and nutritional status of the civilian noninstitutionalized U.S. population and is conducted by the National Center for Health Statistics, part of the Centers for Disease Control and Prevention (CDC). Interviews and physical examinations are conducted with approximately 10,000 people in each two-year survey cycle. CDC's National Center for Environmental Health measures concentrations of environmental chemicals in blood and urine samples collected from NHANES participants. Summaries of the measured values for more than 200 chemicals are provided in the *Fourth National Report on Human Exposure to Environmental Chemicals*.[53]

Mercury

Indicator B3 presents levels of mercury in blood of women of child-bearing age. Organic, inorganic, and total mercury can be measured in blood.[i] The concentration of total mercury in blood is a marker of exposure to methylmercury in populations where fish consumption is the predominant source of mercury exposure. Previous analysis shows that, in general, methylmercury accounts for a large percentage of total mercury in blood among women of child-bearing age in the United States.[47] Total blood mercury is generally representative of methylmercury exposures in the past few months.[54,55] All values are reported as micrograms of mercury per liter of blood (µg/L).

Concentrations of total blood mercury have been measured in all NHANES participants ages 1 to 5 years and all female participants ages 16 to 49 years beginning with the 1999–2000 survey cycle. Starting with the 2003–2004 survey cycle, NHANES measured blood mercury in all participants ages 1 year and older.[56] Separate measurements of inorganic blood mercury have been reported starting with the 2003–2004 NHANES survey cycle.

[i] NHANES also measures mercury levels in participant's urine samples, which is considered a more robust determinant of body burden of mercury from long-term exposure, particularly for inorganic mercury.

For 2009–2010, NHANES collected mercury biomonitoring data for 8,793 individuals ages 1 year and older, including 1,871 women ages 16 to 49 years. Mercury was detected in 81% of all individuals sampled. The frequency of mercury detection was 83% in women ages 16 to 49 years.[ii] The median blood mercury level among all NHANES participants in 2009–2010 was 0.8 µg/L and the 95th percentile was 5.1 µg/L.

Birth Rate Adjustment

Indicator B3 uses measurements of mercury in blood of women ages 16 to 49 years to represent the distribution of mercury exposures to women who are pregnant or may become pregnant. However, blood mercury levels increase with age,[56] and women of different ages have a different likelihood of giving birth. For example, in 2003–2004, women aged 27 years had a 12% annual probability of giving birth, and women aged 37 years had a 4% annual probability of giving birth.[57] A birth rate-adjusted distribution of women's mercury levels is used in calculating this indicator,[iii] meaning that the data are weighted using the age-specific probability of a woman giving birth.[58]

Data Presented in the Indicators

Indicator B3 presents median and 95th percentile concentrations of mercury in blood over time for women ages 16 to 49 years, using NHANES data from 1999–2010.

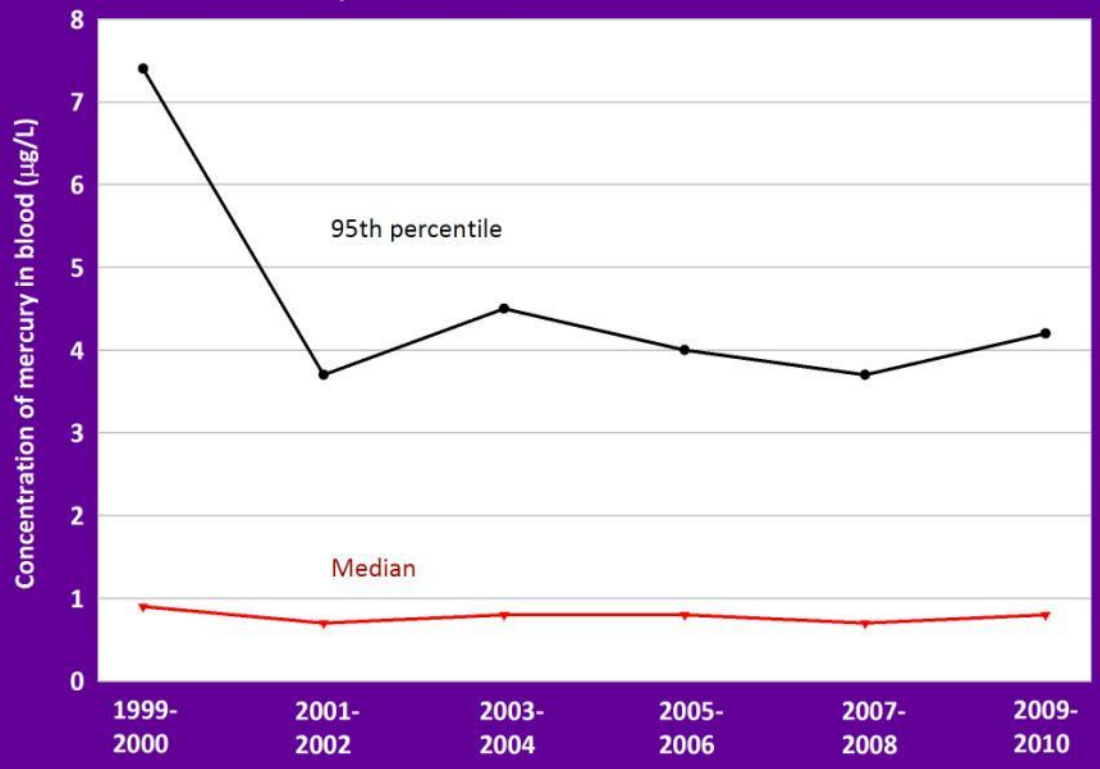
Additional information showing how median and 95th percentile blood mercury levels vary by race/ethnicity and family income for women ages 16 to 49 years is presented in supplemental data tables for these indicators. Data tables also display the median and 95th percentile blood mercury levels for children ages 1 to 5 years over time and the median and 95th percentile blood mercury levels for children ages 1 to 17 years for 2007–2010.

Please see the Introduction to the Biomonitoring section for an explanation of the terms "median" and "95th percentile," a description of the race/ethnicity and income groups used in the ACE3 biomonitoring indicators, and information on the statistical significance testing applied to these indicators.

[ii] The percentage for women ages 16 to 49 years is calculated with the birth rate adjustment described below.
[iii] There may be multiple ways to implement an adjustment to the data that accounts for birth rates by age. The National Center for Health Statistics has not fully evaluated the method used in ACE, or any other method intended to accomplish the same purpose, and has not used any such method in its publications. NCHS and EPA are working together to further evaluate the birth rate adjustment method used in ACE and alternative methods.

Indicator B3

Mercury in women ages 16 to 49 years: Median and 95th percentile concentrations in blood, 1999-2010



Data: Centers for Disease Control and Prevention, National Center for Health Statistics and National Center for Environmental Health, National Health and Nutrition Examination Survey

Note: To reflect exposures to women who are pregnant or may become pregnant, the estimates are adjusted for the probability (by age and race/ethnicity) that a woman gives birth.

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Data characterization

- Data for this indicator are obtained from an ongoing continuous survey conducted by the National Center for Health Statistics.
- Survey data are representative of the U.S. civilian noninstitutionalized population.
- Mercury is measured in blood samples obtained from individual survey participants.

- The median concentration of total mercury in the blood of women ages 16 to 49 years has shown little change between 1999–2000 and 2009–2010, and was 0.8 µg/L in 2009–2010.
- Among women in the 95th percentile of exposure, the concentration of total mercury in blood decreased from 7.4 µg/L in 1999–2000 to 3.7 µg/L in 2001-2002. From 2001–2002 to 2009–2010, the 95th percentile of total blood mercury remained between 3.7 and 4.5 µg/L.

  - The decrease in the 95th percentile levels of blood mercury between 1999–2000 and 2001–2002 was statistically significant. From 2001-2002 to 2009-2010 there was no statistically significant change.
- In 1999–2000, the 95th percentile total mercury level was 8 times the median level. For the remaining years, the 95th percentile total mercury levels were about 5 times the median levels.
- For the years 2007–2010, women of "All Other Races/Ethnicities" had median blood mercury levels of 1.3 µg/L, compared with median mercury levels for the remaining race/ethnicity groups of 0.6–0.8 µg/L. (See Table B3a.)
  - The median blood mercury level in women of "All Other Races/Ethnicities" was statistically significantly higher than the median level for each of the remaining race/ethnicity groups.
- Among women in the 95th percentile of exposure, differences in total mercury in blood were observed across race/ethnicity groups. For the years 2007–2010, White non-Hispanic women had a blood mercury level of 3.7 µg/L, Black non-Hispanics had 2.9 µg/L, Mexican-American women had 2.3 µg/L, and women in the "All Other Races/Ethnicities" group had 6.7 µg/L. (See Table B3b.)
  - The differences between race/ethnicity groups were statistically significant after accounting for differences by income level and age.
- Among women in the 95th percentile of exposure, women living at or above the poverty level had higher blood levels of total mercury (4.0 µg/L) compared with women living below poverty level (2.9 µg/L), a difference that was statistically significant. (See Table B3b.)
- The median and 95th percentile values for women of child-bearing age were about 2 to 4 times those of children ages 1 to 5 years. (See Table B3 and Table B3c.)
- Among children ages 1 to 5 years in the 95th percentile of exposure, the concentration of total mercury in blood showed a decreasing trend from 2.3 µg/L in 1999–2000 to 1.3 µg/L in 2009–2010. The median blood mercury level for children ages 1 to 5 years stayed relatively constant for the same time period. (See Table B3c.)
  - The decreasing trend in 95th percentile blood mercury levels in children was statistically significant. There was no statistically significant change in median blood mercury levels in children.
- Among children ages 1 to 17 years, median and 95th percentile blood mercury levels generally increased with age in 2007–2010, with higher blood mercury levels among children ages 6 years and older. Children ages 16 to 17 years had a median level of mercury in blood of 0.5 µg/L and a 95th percentile of 2.8 µg/L. (See Table B3d.)
  - The differences by age group were statistically significant at both the median and the 95th percentile.

Biomonitoring

Mercury

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Biomonitoring

Mercury

Table B3: Mercury in women ages 16 to 49 years: Median and 95th percentile concentrations in blood, 1999-2010

	Concentration of mercury in blood (µg/L)					
	1999-2000	2001-2002	2003-2004	2005-2006	2007-2008	2009-2010
Median	0.9	0.7	0.8	0.8	0.7	0.8
95th percentile	7.4	3.7	4.5	4.0	3.7	4.2

DATA: Centers for Disease Control and Prevention, National Center for Health Statistics and National Center for Environmental Health, National Health and Nutrition Examination Survey

NOTE: To reflect exposures to women who are pregnant or may become pregnant, the estimates are adjusted for the probability (by age and race/ethnicity) that a woman gives birth. The intent of this adjustment is to approximate the distribution of exposure to pregnant women. Results will therefore differ from a characterization of exposure to adult women without consideration of birth rates.

Table B3a. Mercury in women ages 16 to 49 years: Median concentrations in blood, by race/ethnicity and family income, 2007-2010

	Median concentration of mercury in blood (µg/L)		
Race / Ethnicity	**All Incomes‡** *(n=3,456)*	**< Poverty Level** *(n=915)*	**≥ Poverty Level** *(n=2,261)*
All Races/Ethnicities *(n=3,456)*	0.7	0.6	0.8
White non-Hispanic *(n=1,430)*	0.7	0.5	0.7
Black non-Hispanic *(n=665)*	0.8	0.8	0.9
Mexican-American *(n=722)*	0.6	0.6	0.7
All Other Races/Ethnicities† *(n=639)*	1.3	0.8	1.5

DATA: Centers for Disease Control and Prevention, National Center for Health Statistics and National Center for Environmental Health, National Health and Nutrition Examination Survey

NOTE: To reflect exposures to women who are pregnant or may become pregnant, the estimates are adjusted for the probability (by age and race/ethnicity) that a woman gives birth. The intent of this adjustment is to approximate the distribution of exposure to pregnant women. Results will therefore differ from a characterization of exposure to adult women without consideration of birth rates.

† The "All Other Races/Ethnicities" category includes all other races or ethnicities not specified, together with those individuals who report more than one race.

‡ Includes sampled individuals for whom income information is missing.

Table B3b. Mercury in women ages 16 to 49 years: 95th percentile concentrations in blood, by race/ethnicity and family income, 2007-2010

	95th percentile concentration of mercury in blood (µg/L)		
Race / Ethnicity	**All Incomes‡** *(n=3,456)*	**< Poverty Level** *(n=915)*	**≥ Poverty Level** *(n=2,261)*
All Races/Ethnicities *(n=3,456)*	3.9	2.9	4.0
White non-Hispanic *(n=1,430)*	3.7	2.9	3.7
Black non-Hispanic *(n=665)*	2.9	2.3	3.3
Mexican-American *(n=722)*	2.3	1.9	2.4
All Other Races/Ethnicities† *(n=639)*	6.7	NA**	6.5

DATA: Centers for Disease Control and Prevention, National Center for Health Statistics and National Center for Environmental Health, National Health and Nutrition Examination Survey

NOTE: To reflect exposures to women who are pregnant or may become pregnant, the estimates are adjusted for the probability (by age and race/ethnicity) that a woman gives birth. The intent of this adjustment is to approximate the distribution of exposure to pregnant women. Results will therefore differ from a characterization of exposure to adult women without consideration of birth rates.

† The "All Other Races/Ethnicities" category includes all other races or ethnicities not specified, together with those individuals who report more than one race.

‡ Includes sampled individuals for whom income information is missing.

** Not available. The estimate is not reported because it has large uncertainty: the relative standard error, RSE, is 40% or greater (RSE = standard error divided by the estimate), or the RSE cannot be reliably estimated.

Table B3c: Mercury in children ages 1 to 5 years: Median and 95th percentile concentrations in blood, 1999-2010

	Concentration of mercury in blood (µg/L)					
	1999-2000	**2001-2002**	**2003-2004**	**2005-2006**	**2007-2008**	**2009-2010**
Median	0.3	0.3	0.3	0.2	0.2	0.2
95th percentile	2.3	1.9	1.8	1.4	1.3	1.3

DATA: Centers for Disease Control and Prevention, National Center for Health Statistics and National Center for Environmental Health, National Health and Nutrition Examination Survey

Table B3d: Mercury in children ages 1 to 17 years: Median and 95th percentile concentrations in blood, by age group, 2007-2010

	Concentration of mercury in blood (µg/L)						
	Ages 1 to 17 years	**Age 1 year**	**Age 2 years**	**Ages 3 to 5 years**	**Ages 6 to 10 years**	**Ages 11 to 15 years**	**Ages 16 to 17 years**
Median	0.4	0.2	0.2	0.2	0.4	0.4	0.5
95th percentile	1.9	1.2	1.3	1.4	1.7	2.2	2.8

DATA: Centers for Disease Control and Prevention, National Center for Health Statistics and National Center for Environmental Health, National Health and Nutrition Examination Survey