Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a family of industrial chemicals that were produced in the United States from 1929 to 1979 and used primarily as insulating fluids in capacitors, transformers, and other electrical equipment.[1] PCBs were also used as plasticizers in many paints, plastics, and rubber products, and had numerous applications in industry and building construction.[1]

Each PCB has a common structure of a biphenyl molecule with 1 to 10 chlorine atoms attached; each possible variant is called a congener. In theory, there could be as many as 209 PCB congeners; however, a smaller number of congeners were found in manufactured PCB mixtures, and measurements of PCBs in the environment and in human blood samples typically target a subset of the congeners.[2,3]

The PCB congeners are sometimes separated into two categories, "dioxin-like" or "non-dioxin-like," that are defined by structural differences and that act by different toxicological mechanisms.[4,5] The dioxin-like PCBs are structurally and toxicologically related to the chemical 2,3,7,8- tetrachlorodibenzo-p-dioxin, which has been studied very extensively in toxicological and epidemiological research. However, both categories have been associated with adverse health outcomes and it is unknown which congeners are the most potent, particularly for outcomes most relevant to children's health.[2,4]

Manufacture, sale, and use of PCBs was generally banned in the United States in 1979,[6] but EPA regulations have authorized their continued use in certain equipment manufactured prior to the ban. Due to their persistent nature, PCBs remain widely distributed in the environment, and they are also present at many Superfund sites.[2] The persistent nature of PCBs and their distribution through the food chain has resulted in continuing human exposure. However, dietary intake of PCBs and levels measured in blood serum have declined since the ban.[2,7,8] Measured levels of PCBs in human blood decreased by an estimated 87% from 1973–2003,[7] and levels of PCB-153, one of the major PCB congeners, also showed significant decline from the late 1980s to 2002.[8] Although levels of PCBs in environmental samples have declined from their peak, the rate of decline has slowed in recent years.[9,10]

A large body of health effects research comes from children born to mothers who were exposed to high concentrations of a mixture of PCBs and polychlorinated dibenzofurans (a class of dioxin-like chemicals) in accidental poisoning incidents in Taiwan and Japan. These prenatally exposed children exhibited a number of adverse health effects, including neurodevelopmental effects such as cognitive deficits, developmental delays, effects on motor skills, behavioral effects, immunological effects, and skin alterations ranging from irritation to chloracne,[2] a potentially serious inflammatory condition.[11-16]

Following the poisoning incidents, several studies have been conducted to examine the effects of PCBs at more typical exposure levels. Many of these studies have linked early-life exposure

to PCBs with neurodevelopmental effects, such as lowered intelligence, and behavioral deficits, including inattention and impulsive behavior.[17-23] The observed effects have been most frequently associated with exposure in the womb resulting from the mother having eaten food contaminated with PCBs,[24-29] but some studies have detected relationships between adverse effects and PCB exposure during infancy and childhood.[22,29-31] Although there is some inconsistency in the epidemiological literature, several reviews of the literature have concluded that the overall evidence supports a concern for effects of PCBs on children's neurological development.[16,30,32-34] The Agency for Toxic Substances and Disease Registry has determined that "Substantial data suggest that PCBs play a role in neurobehavioral alterations observed in newborns and young children of women with PCB burdens near background levels."[2] Research on dioxin-like chemicals in general also supports a concern for neurodevelopmental effects from the dioxin-like PCBs.[35] Similar outcomes have been observed in experimental animal studies, including behavioral changes and learning deficits in rats and monkeys exposed to PCBs in their diets.[2,36]

Prenatal PCB exposures have also been associated with immunological effects, such as increased infections, in multiple epidemiological studies,[37-43] with supporting evidence from the literature on effects of dioxin-like chemicals.[35] Possible other effects of exposure to PCBs—with limited or inconclusive evidence—include preterm birth and low birthweight,[16] as well as effects on the timing of puberty in both boys and girls.[44] PCBs are also considered "reasonably anticipated to be human carcinogens," based on experimental animal studies.[45]

Biomonitoring data in U.S. children under 12 years of age is limited. One study of 6- to 9-year-old girls from 2005–2007 in California and Ohio showed a median level of PCB-153, the congener with the highest concentration, of 7.4 nanograms per gram of lipid (ng/g lipid). The same congener was measured in a nationally representative sample of the U.S. population ages 12 years and older in 2003–2004. The median level of PCB-153 in males and females ages 12 to 19 years was 5.4 ng/g lipid and for adults ages 20 years and over the median level was 24.2 ng/g lipid.[46,47]

Due to the continued presence of PCBs in fish, especially salmon, meat, poultry, dairy products, and breast milk,[48] dietary intake is an important pathway of exposure for PCBs.[2] In infants, dietary intake is important since PCBs accumulate in the mother's body over many years and are stored in the fat in breast milk,[35] and breast-feeding infants are exposed to the PCBs in the milk.[49] PCBs can also cross the placental barrier to transfer prenatally from mother to fetus, and PCBs have been measured in cord blood.[2,50]

Recent findings also suggest that the presence of PCBs in indoor dust and indoor air may constitute an important exposure pathway for some portion of the population.[51-54] The importance of PCBs in indoor environments may be greater for toddlers than for adults and children of other ages, because toddlers tend to have more contact with house dust.[51] A study of homes with unusually high indoor air concentrations of PCBs found that a PCB-containing wood flooring finish applied in the 1950s and 1960s can be a major contributor to current elevations of PCBs in blood for people living in those homes.[53] PCBs have been found in caulk in

some schools and other buildings constructed or renovated before the late 1970s, which may contribute significantly to indoor air and dust levels of PCBs in those buildings.[55,56] Many schools have lighting systems containing PCBs that were produced before PCBs were banned. While well-contained lighting systems pose little risk, the PCB-containing ballasts are only expected to last 10–15 years. Existing ballasts from before the ban are past their life expectancy and are at a greater risk for leaks and fires, resulting in a greater risk of PCB exposure.[57] Finally, the inadvertent presence of PCBs has been found in pigments that are currently manufactured for use in paints, inks, textiles, paper, cosmetics, leather, and other materials.[58,59]

Blood levels of PCBs generally increase with age, because these chemicals are persistent.[60,61] However, the decline in levels of PCBs in the environment and in foods over the past three decades, suggests that young people today are exposed to lower levels of PCBs through the diet than were previous generations.[2,7,9,10]

Although environmental levels of PCBs have been declining, there are concerns that some past PCB emissions trapped in polar ice may be released to the environment in coming years with increasing ice melts.[62,63] Furthermore, environments where heavy PCB contamination previously occurred continue to be remediated, which may dislodge or expose additional PCBs. The Hudson River, contaminated with 1.3 million pounds of PCBs between 1947 and 1977, is undergoing remediation to remove PCB-contaminated sediments. After Phase 1 of the remediation in 2009 there was a short-term increase in the PCB levels in fish samples, but more recent samples from 2010 did not have increased PCB concentrations.[64,65]

The following indicator presents the best nationally representative data on PCB levels in women of child-bearing age. Indicator B7 presents median blood serum levels of PCBs for women ages 16 to 49 years. Although data are available only for two two-year survey periods at this time, the data provide a baseline that will be updated with PCB measurements over time from subsequent survey cycles. No indicator is presented for PCBs in children due to the limited availability of data.

Indicator B7: PCBs in women ages 16 to 49 years: Median concentrations in blood serum, by race/ethnicity and family income, 2001–2004

About the Indicator: Indicator B7 presents concentrations of PCBs in blood serum 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 PCBs in the blood serum. The indicator presents comparisons of PCBs in blood serum for women of different race/ethnicities, and for women of different income levels. 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 PCBs.

NHANES

The National Health and Nutrition Examination Survey (NHANES) provides nationally representative biomonitoring data for PCBs. 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*.[46]

PCB Congeners

Indicator B7 presents blood serum levels of PCBs in women of child-bearing age. There are 209 possible PCBs, referred to as "congeners," which are defined by the number of chlorine atoms (from 1 to 10) and their position in the chemical structure. Most of these congeners were not present in the manufactured PCB mixtures and have not been measured in environmental or human samples.

PCB concentrations are measured in blood serum. PCBs are lipophilic, meaning that they tend to accumulate in fat. Serum PCB concentrations are measured and expressed on a lipid-adjusted basis, as these values better represent the amount of PCBs stored in the body compared with unadjusted values.[46] The indicator uses lipid-adjusted concentrations, meaning that the concentration of PCBs in serum is divided by the concentration of lipid in serum. The resulting units are nanograms of PCB per gram of lipid (ng/g lipid) in serum.[i]

Concentrations of PCBs in blood serum have been measured in a representative subset of NHANES participants ages 12 years and older beginning with the 1999–2000 survey cycle.

[i] Serum levels of PCBs can also be reported without lipid adjustment. Both the lipid-adjusted values and the unadjusted "whole weight" values are reported in CDC's *Fourth National Report on Human Exposure to Environmental Chemicals*.

NHANES sampled for 34 PCB congeners in 2001–2002, and added 4 congeners in 2003–2004 for a total of 38 congeners. Indicator B7 uses NHANES data on four specific congeners: PCBs 118, 138, 153, and 180. These four congeners are generally found at higher levels in the environment—and in human blood samples—than other PCB congeners. This combination of congeners has been frequently used to represent PCB exposure in the epidemiological studies described above that identified children's health concerns for PCBs. PCBs 118, 138, 153, and 180 were detected in the majority of samples for women ages 16 to 49 years in 2001–2002, and in virtually all samples for this population group in 2003–2004.

Indicator B7 was calculated by summing together the measured values of the 4 selected congeners for each woman 16 to 49 years sampled in NHANES; this approach is commonly used in studies assessing levels of PCBs in human blood samples and environmental samples.[2,30] If the congener was not detected in a sample, a default value below the detection limit was assigned for purposes of calculating the summed total.[ii] This assumption has a small impact on the indicator values, because all four congeners were detected in most samples in the combined four-year (2001–2004) data set.

In 2001–2004, a sum of measured PCBs 118, 138, 153, and 180 is available from NHANES for 4,205 individuals ages 12 years and older, including 1164 women ages 16 to 49 years. The four selected PCBs were detected in 81% of the individuals sampled in NHANES 2001-2004,[iii] and in 71% of women ages 16 to 49 years.[iv] The median sum of the four PCB congeners in blood serum among all NHANES participants in 2001-2004 was 71 ng/g lipid and the 95th percentile sum was 316 ng/g lipid.

Birth Rate Adjustment

Indicator B7 uses measurements of PCBs in the blood of women ages 16 to 49 years to represent the distribution of PCB exposures to women who are pregnant or may become pregnant. However, 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.[66] A birth rate-adjusted distribution of women's PCB levels is used in calculating this indicator,[v] meaning that the data are weighted using the age-specific probability of a woman giving birth.[67]

[ii] The default value used for non-detect samples is equal to the limit of detection divided by the square root of 2.
[iii] In 2003–2004, PCBs were detected in 100% of the individuals sampled. The detection frequency was lower in 2001–2002 due to use of less sensitive measurement techniques.
[iv] The percentage for women ages 16 to 49 years is calculated with the birth rate adjustment described below.
[v] 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.

Data Presented in the Indicator

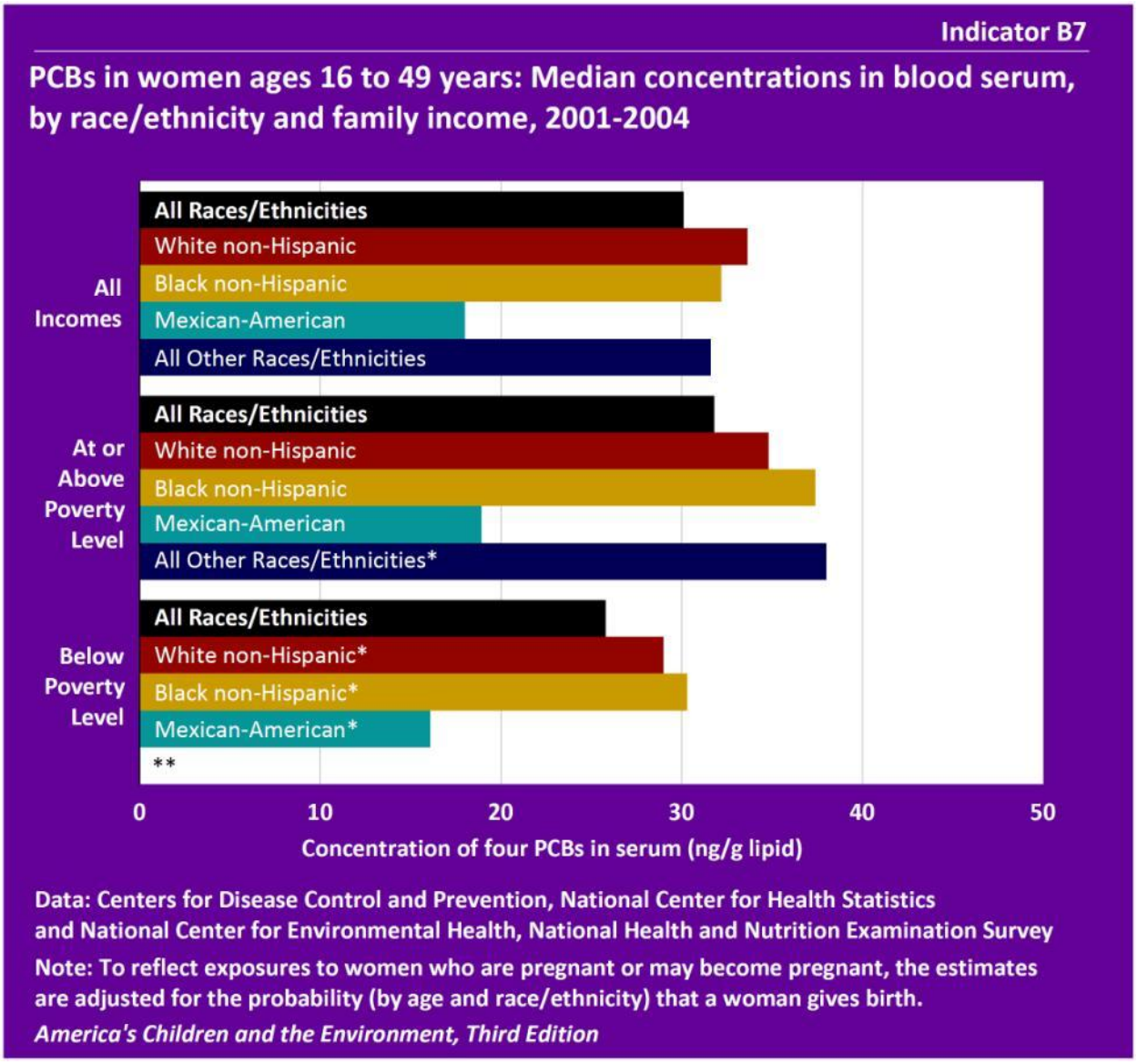
Indicator B7 presents median concentrations of PCBs in blood serum, computed as the sum of PCBs 118, 138, 153, and 180, for women ages 16 to 49 years of different races/ethnicities and levels of family income, using NHANES data from 2001–2002 and 2003–2004.

Data from 1999–2000 are not included in the indicator because less sensitive measurement techniques were used in those years, and PCB levels could not be determined in a large proportion of the blood samples. Improvements in measurement sensitivity were achieved in 2001–2002, with further improvements in 2003–2004 resulting in the detection of PCBs in a majority of samples.[61] The data from the 2001–2002 and 2003–2004 NHANES cycles are combined to increase the statistical reliability of the estimates for each race/ethnicity and income group, and to reduce any possible influence of geographic variability that may occur in two-year NHANES data. No time series is shown because data from only two NHANES cycles are too limited to depict possible changes over time.

Four race/ethnicity groups are presented in Indicator B7: White non-Hispanic, Black non-Hispanic, Mexican-American, and "All Other Races/Ethnicities." The "All Other Races/Ethnicities" category includes all other races and ethnicities not specified, together with those individuals who report more than one race. The limits of the sample design and sample size often prevent statistically reliable estimates for smaller race/ethnicity groups. The data are also tabulated across three income categories: all incomes, below the poverty level, and greater than or equal to the poverty level.

Additional information on how 95th percentile blood serum levels of PCBs vary by race/ethnicity and family income for women ages 16 to 49 years is presented in the supplemental data tables for this indicator

Please see the Introduction to the Biomonitoring section for an explanation of the terms "median" and "95th percentile," along with information on the statistical significance testing applied to these indicators.



*The estimate should be interpreted with caution because the standard error of the estimate is relatively large: the relative standard error, RSE, is at least 30% but is less than 40% (RSE = standard error divided by the estimate), or the RSE may be underestimated.

** 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.

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.
- PCBs are measured in blood samples obtained from individual survey participants.

- In 2001–2004, the median level of PCBs in blood serum among women ages 16 to 49 years (the sum of PCBs 118, 138, 153 and 180) was 30 ng/g lipid.
- Median PCB levels were higher for women with higher incomes than for women with lower incomes, consistently for all race/ethnicity groups.
  - After accounting for other demographic differences (i.e., differences in age profile), the differences between income levels for each race/ethnicity group were not statistically significant except for the differences for White non-Hispanic women.
- Median PCB levels were lower among Mexican-American women than among women of any other race/ethnicity group.
  - These differences were statistically significant. After accounting for other demographic differences (i.e., differences in income or age profile), the differences remained statistically significant except for that between Mexican-American women and women of "All Other Races/Ethnicities."
- The 95th percentile concentration of PCBs among women ages 16 to 49 years was 106 ng/g lipid. Among women of "All Other Races/Ethnicities," the 95th percentile PCB concentration was substantially higher, at 245 ng/g lipid; the 95th percentile concentration among Mexican-American women was substantially lower at 49 ng/g lipid. (See Table B7a.)
  - These differences were statistically significant: the 95th percentile for women of "All Other Races/Ethnicities" was greater than the value for each of the remaining race/ethnicities; and the 95th percentile for Mexican-American women was less than the value for each of the remaining race/ethnicities.

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Polychlorinated Biphenyls (PCBs)

Table B7. PCBs in women ages 16 to 49 years: Median concentrations in blood serum, by race/ethnicity and family income, 2001-2004

	Median concentration of PCBs in serum (ng/g lipid)		
Race / Ethnicity	**All Incomes‡** *(n=1,164)*	**< Poverty Level** *(n=299)*	**≥ Poverty Level** *(n=810)*
All Races/Ethnicities *(n=1,164)*	30.1	25.8	31.8
White non-Hispanic *(n=477)*	33.6	29.0*	34.8
Black non-Hispanic *(n=281)*	32.2	30.3*	37.4
Mexican-American *(n=305)*	18.0	16.1*	18.9
All Other Races/Ethnicities† *(n=101)*	31.6	NA**	38.0*

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

NOTES:

- Values below the limit of detection are assumed equal to the limit of detection divided by the square root of 2.
- 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.

*The estimate should be interpreted with caution because the standard error of the estimate is relatively large: the relative standard error, RSE, is at least 30% but is less than 40% (RSE = standard error divided by the estimate), or the RSE may be underestimated.

** 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 B7a. PCBs in women ages 16 to 49 years: 95th percentile concentrations in blood serum, by race/ethnicity and family income, 2001-2004

	95th percentile concentration of PCBs in serum (ng/g lipid)		
Race / Ethnicity	**All Incomes‡** *(n=1,164)*	**< Poverty Level** *(n=299)*	**≥ Poverty Level** *(n=810)*
All Races/Ethnicities *(n=1,164)*	106.2	87.6	111.3
White non-Hispanic *(n=477)*	108.7	87.6*	114.6
Black non-Hispanic *(n=281)*	101.8	74.3*	118.0
Mexican-American *(n=305)*	49.1	NA**	58.1
All Other Races/Ethnicities† *(n=101)*	245.2	NA**	191.3*

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

NOTES:

- Values below the limit of detection are assumed equal to the limit of detection divided by the square root of 2.
- 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.

*The estimate should be interpreted with caution because the standard error of the estimate is relatively large: the relative standard error, RSE, is at least 30% but is less than 40% (RSE = standard error divided by the estimate), or the RSE may be underestimated.

** 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.