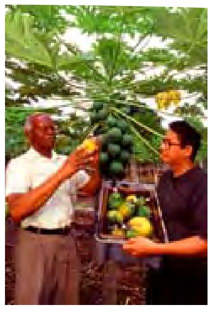
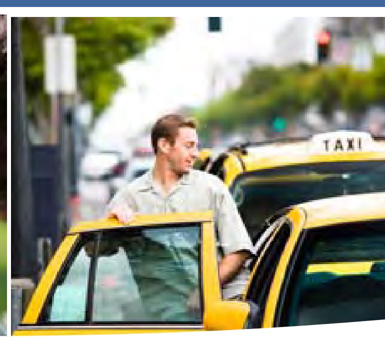
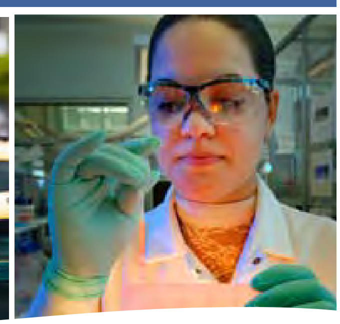



2009

Fourth National Report on Human Exposure to Environmental Chemicals







Fourth National Report on Human Exposure to Environmental Chemicals

2009

Department of Health and Human Services
Centers for Disease Control and Prevention

Contents

Introduction

The *Fourth National Report on Human Exposure to Environmental Chemicals, 2009* (the *Report)* provides an ongoing assessment of the exposure of the U.S. population to environmental chemicals by the use of biomonitoring. The *Report* is cumulative (containing all the results from previous *Reports*) and provides new data for years 2003-2004. Data for 75 new environmental chemicals are included for the survey period 2003-2004. The *Report* website http://www.cdc.gov/exposurereport is also the best source for the most recent update of available data.

In each survey period, most chemicals or their metabolites were measured in blood, serum, and urine samples from random subsamples of about 2500 participants from the National Health and Nutrition Examination Survey (NHANES) conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics. NHANES is a series of surveys designed to collect data related to the health and nutritional status of the U.S. population. The blood, serum, and urine exposure measurements presented in the *Report* were made by CDC's Environmental Health Laboratory (Division of Laboratory Sciences, National Center for Environmental Health) using mass spectrometry methods.

The term *environmental chemical* refers to a chemical compound or chemical element present in air, water, food, soil, dust, or other environmental media (e.g., consumer products). Biomonitoring is the assessment of human exposure to chemicals by measuring the chemicals or their metabolites in such human specimens as blood or urine. A metabolite is a chemical alteration of the original compound produced by body tissues. Blood, serum, and urine levels reflect the amount of a chemical that actually gets into the body by all routes of exposure, including ingestion, inhalation, and dermal absorption. The measurement of an environmental chemical in a person's blood or urine is an indication of exposure; it does not by itself mean that the chemical causes disease or an adverse effect. Research studies, separate from these data, are required to determine which blood or urine levels are safe and which are associated with disease or an adverse effect. For blood, serum, and urine levels, the *Report* provides geometric means and percentiles of environmental chemicals by age group, gender and race/ethnicity. More in-depth statistical analysis, including multivariate analysis incorporating health endpoints and other predictive variables, is beyond the scope of this document. We encourage scientists to examine the data further through analysis of the raw data available at http://www.cdc.gov/nchs/nhanes.htm.

Public Health Uses of the *Report*

The overall purpose of the *Report* is to provide unique exposure information to scientists, physicians, and health officials to help prevent exposure to some environmental chemicals. Specific public health uses of the exposure information in the *Report* are

- To determine which chemicals get into Americans and at what concentrations.
- For chemicals with a known toxicity level, to determine the prevalence of people with levels above those toxicity levels (e.g., a blood lead level greater than or equal to 10 micrograms per deciliter [≥ 10 µg/dL]).
- To establish reference values that can be used by physicians and scientists to determine whether a person or group has an unusually high exposure. This information is especially helpful to identify population groups that merit further assessment of exposure sources or health effects.
- To assess the effectiveness of public health efforts to reduce exposure of Americans to specific chemicals.
- To determine whether exposure levels are higher among such potentially vulnerable groups as minorities and children.
- To track, over time, trends in levels of exposure of the population.
- To set priorities for research on human health effects.

What's New in this *Report*

In this *Fourth Report*, 75 new chemicals are added for the 2003-2004 survey period and are listed in Table 1. The process for selection is described at http://www.cdc.gov/exposurereport/chemical_selection.html.

Table 1. Chemicals reported for the first time in the *Fourth National Report on Human Exposure to Environmental Chemicals, 2009*

Acrylamide Adducts
Acrylamide
Glycidamide

Total and Speciated Arsenic
Arsenic, Total
Arsenic (V) acid
Arsenobetaine
Arsenocholine
Arsenous (III) acid
Dimethylarsinic acid
Monomethylarsonic acid
Trimethylarsine oxide

Disinfection By-Products (Trihalomethanes)
Bromodichloromethane
Dibromochloromethane (Chlorodibromomethane)
Bromoform (Tribromomethane)
Chloroform (Trichloromethane)

Environmental Phenols
Benzophenone-3 (2-Hydroxy-4-methoxybenzophenone)
Bisphenol A (2,2-*bis*[4-Hydroxyphenyl] propane)
4-*tert*-Octyl phenol (4-[1,1,3,3-Tetramethylbutyl] phenol)
Triclosan (2,4,4'-Trichloro-2'-hydroxyphenyl ether)

Non-dioxin-like Polychlorinated Biphenyls
2,2'3,5'-Tetrachlorobiphenyl (PCB 44)
2,2'4,5'-Tetrachlorobiphenyl (PCB 49)
2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl (PCB 209)

Perchlorate

Perfluorinated Compounds
Perfluorobutane sulfonic acid (PFBuS)
Perfluorodecanoic acid (PFDeA)
Perfluorododecanoic acid (PFDoA)
Perfluoroheptanoic acid (PFHpA)
Perfluorohexane sulfonic acid (PFHxS)
Perfluorononanoic acid (PFNA)
Perfluorooctane sulfonamide (PFOSA)
Perfluorooctane sulfonic acid (PFOS)
2-(N-Ethyl-Perfluorooctane sulfonamido) acetic acid (Et-PFOSA-AcOH)
2-(N-Methyl-perfluorooctane sulfonamido) acetic acid (Me-PFOSA-AcOH)
Perfluorooctanoic acid (PFOA)
Perfluoroundecanoic acid (PFUA)

Phthalate Metabolite
Mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP)

Polybrominated Diphenyl Ethers (PBDE) and Polybrominated Biphenyl
2,2',4-Tribromodiphenyl ether (BDE 17)
2,4,4'-Tribromodiphenyl ether (BDE 28)
2,2',4,4'-Tetrabromodiphenyl ether (BDE 47)
2,3',4,4'-Tetrabromodiphenyl ether (BDE 66)
2,2',3,4,4'-Pentabromodiphenyl ether (BDE 85)
2,2',4,4',5-Pentabromodiphenyl ether (BDE 99)
2,2',4,4',6-Pentabromodiphenyl ether (BDE 100)
2,2',4,4',5,5'-Hexabromodiphenyl ether (BDE 153)
2,2',4,4',5,6'-Hexabromodiphenyl ether (BDE 154)
2,2',3,4,4',5',6-Heptabromodiphenyl ether (BDE 183)
2,2',4,4',5,5'-Hexabromobiphenyl (BB 153)

Volatile Organic Compounds (VOCs)
Benzene
Chlorobenzene (Monochlorobenzene)
1,2-Dibromo-3-chloropropane (DBCP)
Dibromomethane
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, Paradichlorobenzene)
1,1-Dichloroethane
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethene (Vinylidene chloride)
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
Dichloromethane (Methylene chloride)
1,2-Dichloropropane
2,5-Dimethylfuran
Ethylbenzene
Hexachloroethane
Methyl-*tert*-butyl ether (MTBE)
Nitrobenzene
Styrene
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Tetrachloromethane (Carbon tetrachloride)
Toluene
1,1,1-Trichloroethane (Methyl chloroform)
1,1,2-Trichloroethane
Trichloroethene (Trichloroethylene)
m- and *p*-Xylene
o-Xylene

What's Different in this *Report*

The *Fourth Report* uses a new procedure to estimate percentiles when the percentile estimate falls on a value that is repeated multiple times (e.g., five results that all have the value 90.1). Percentiles for all three NHANES survey periods (1999-2000, 2001-2002, 2003-2004) have been re-computed by use of this improved procedure. Only slight differences should be noted when one compares the recomputations to previous releases of the *Report*. Details of this procedure are provided in Appendix A.

2003-2004 data for the organochlorine pesticides and the dialkyl phosphate organophosphorus insecticides are included in the *Report*. Data for other pesticides are included only for 1999-2000 and 2001-2002. 2003-2004 data for these other pesticides will be provided on this website as soon as they are available, and these data will be included in the next release of the *Report*.

Some results reported previously have been changed or removed due to improvements in analytical measurement or recognition of an analytical issue (e.g., the presence of an interference) that produced results of inadequate quality. Affected analytes were serum *beta*-hexachlorocyclohexane for the 2001-2002 survey period; urinary 2,4-dichlorophenol and 2,5-dichlorophenol for the 1999-2002 survey periods; and polycyclic aromatic hydrocarbons (PAHs) for one or more of the 1999-2002 survey periods. Explanations for each change are provided in Appendix B.

Data Sources and Data Analysis

Blood, serum, and urine samples from NHANES

Biomonitoring measurements for the *Report* were made in samples from participants in NHANES. NHANES is a series of surveys conducted by CDC's National Center for Health Statistics (NCHS). NHANES is designed to collect data on the health and nutritional status of the U.S. population. NHANES collects information about a wide range of health-related behaviors, performs physical examinations, and collects samples for laboratory tests. NHANES is unique in its ability to examine public health issues in the U.S. population, such as risk factors for cardiovascular disease. Beginning in 1999, NHANES became a continuous survey, sampling the U.S. population annually and releasing the data in 2-year cycles. The sampling plan follows a complex, stratified, multistage, probability-cluster design to select a representative sample of the civilian, noninstitutionalized population in the United States based on age, gender, and race/ethnicity.

The NHANES protocol includes a home interview followed by a standardized physical examination in a mobile examination center. As part of the examination component, blood is obtained by venipuncture from participants aged 1 year and older, and urine specimens are collected from participants aged 6 years and older. Additional detailed information on the design and conduct of the NHANES survey is available at http://www.cdc.gov/nchs/nhanes.htm.

Environmental chemicals were measured in blood, serum, or urine specimens collected as part of the examination component of NHANES. The participant ages for which a chemical was measured varied by chemical group. Most of the environmental chemicals were measured in randomly selected subsamples within specific age groups. Randomization of subsample selection is built into the NHANES design before sample collection begins. Different random subsamples include different participants. This subsampling was needed to ensure an adequate quantity of sample for analysis and to accommodate the throughput of the mass spectrometry analytical methods.

Age groups and sample sizes for each exposure measurement are provided in each of the data tables. Blood lead and blood cadmium were measured in all participants aged 1 year and older for all survey periods. Total blood mercury was measured in children aged 1-5 years and in women aged 16-49 years in 1999-2002. Total blood mercury and inorganic blood mercury were measured in all participants aged 1 year and older in 2003-2004. Urinary mercury was measured in women aged 16-49 years in 1999-2002. For the 2003-2004 survey, urinary mercury was measured in a random one-third subsample of participants aged 6 years and older. Serum cotinine and acrylamide adducts were measured in the entire NHANES sample for ages 3 years and older. Cotinine is reported only in nonsmokers.

Though most chemicals in urine were measured in a random one-third subsample of participants aged 6 years and older, there have been some exceptions. Urinary levels of herbicides, selected pesticides, and metabolites of organophosphate pesticides were measured in a random one-half subsample of children aged 6-11 years in 1999 and 2000; in a random one-quarter subsample of people aged 12-59 years in 1999; and in a random one-third subsample of people aged 12 years and older in 2000. Otherwise in 2001-2002 and 2003-2004, these chemicals were measured in a random one-third subsample of participants aged 6 years and older.

Dioxins, furans, polychlorinated biphenyls (PCBs), and organochlorine pesticides were measured in serum from a random one-third subsample of participants aged 12 years and older in 1999-2000 and 2003-2004. In 2001-2002, dioxins, furans, and coplanar PCBs were measured in a random one-third subsample of participants aged 20 years and older, while organochlorine pesticides and other PCBs were measured in a random one-third subsample of participants aged 12 years and older.

Chemicals in the *Report* were selected on the basis of scientific data that suggested exposure in the U.S. population; the seriousness of health effects known or suspected to result from some levels of exposure; the need to assess the effectiveness of public health actions to reduce exposure to a chemical; the availability of a biomonitoring analytical method with adequate accuracy, precision, sensitivity, specificity, and throughput; the availability of adequate blood or urine samples; and the incremental analytical cost to perform the biomonitoring analysis for the chemical. The availability of biomonitoring methods with adequate performance and acceptable cost was a major consideration. Details on the prioritization process for scoring nominated chemicals and the resulting scores are available at http://www.cdc.gov/exposurereport/chemical_selection.html.

Laboratory Analysis

The blood, serum and urine exposure measurements in the *Report* were made by CDC's Environmental Health Laboratory (Division of Laboratory Sciences, National Center for Environmental Health). The analytical methods used for measuring the environmental chemicals or their metabolites in blood, serum, and urine were based on isotope dilution mass spectrometry, inductively coupled plasma mass spectrometry, or graphite furnace atomic absorption spectrometry. Laboratory measurements underwent extensive quality control and quality assurance review, including tolerance limits for operational parameters, the measurement of quality control samples in each analytical run to detect unacceptable performance in accuracy or precision, and verification of traceable calibration materials. References for the analytical methods used to measure the different chemicals are provided in Appendix C.

Data Analysis

Because the NHANES is a complex, stratified, multistage, probability-cluster design, sample weights must be used to adjust for the unequal probability of selection into the survey. Sample weights also are used to adjust for possible bias resulting from nonresponse and are post-stratified to U.S. Census Bureau estimates of the U.S. population. Data were analyzed using the statistical software package Statistical Analysis System (SAS) (SAS Institute Inc., 2002) and the statistical software package SUDAAN (SUDAAN Release 8.0, 2001). SUDAAN uses sample weights and calculates variance estimates that account for the complex survey design. This design does not permit straightforward analysis of exposure levels by non-targeted strata such as locality, state, or region; seasons of the year; proximity to sources of exposure; or by use of particular products. Guidelines for the analysis of NHANES data are provided by NCHS at http://www.cdc.gov/nchs/nhanes/nhanes2003-2004/analytical_guidelines.htm.

The *Report* presents descriptive statistics on the blood, serum, or urine levels for each environmental chemical. Statistics include unadjusted geometric means and percentiles with confidence intervals. In each table, results are given for the total population as well as by age group, gender, and race/ethnicity as defined in NHANES. For these analyses, race/ethnicity is categorized based on the sample design as Mexican American, non-Hispanic black, and non-Hispanic white. Other racial/ethnic groups are sampled, but the proportion of the total population represented by other racial/ethnic groups is not large enough to produce valid estimates. Other racial/ethnic groups are included in estimates that are based on the entire population sample. Age groups are as described for each chemical in each data table. Gender is coded as male or female.

Units: For chemicals measured in urine, levels are presented two ways: per volume of urine and per gram of creatinine. Urinary levels are expressed both ways in the literature and used for different purposes. Levels per gram of creatinine (i.e., creatinine corrected) adjust for urine dilution. For example, if one person has consumed more fluids than another person, his or her urine output is likely higher and the urine more dilute than that of the other person. Interpretation of creatinine corrected results should also recognize that creatinine correction can also partially adjust for differences in lean body mass or renal function among persons.

For dioxins, furans, PCBs, and organochlorine pesticides, serum levels are presented per gram of total lipid and per whole weight of serum. These compounds are lipophilic and concentrate in the body's lipid stores, including the lipid in serum. Serum levels reported per gram of total lipid reflect the amount of these compounds that are stored in body fat. Serum levels per whole weight of serum are also included to facilitate comparison with studies investigating exposure to these chemicals and reported levels in these units. Other mostly non-lipophilic chemicals measured in serum are expressed per liter of serum (e.g., micrograms per liter). Acrylamide and glycidamide adducts are expressed as the picomoles per gram of blood hemoglobin to which the adduct is bound.

Units of measurement are important. Results are reported here using standard units, generally conforming to those most commonly used in biomonitoring measurements. Useful unit conversions are shown in Table 2.

Table 2. Units of Measurements and Abbreviations

Unit	Abbreviation	Value
liter	L	
deciliter	dL	10^{-1} liters
milliliter	mL	10^{-3} liters
gram	g	
milligram	mg	10^{-3} grams
microgram	µg	10^{-6} grams
nanogram	ng	10^{-9} grams
picogram	pg	10^{-12} grams
femtogram	fg	10^{-15} grams

Geometric means: A geometric mean provides a better estimate of central tendency for data that are distributed with a long tail at the upper end of the distribution. This type of distribution is common in the measurement of environmental chemicals in blood or urine. The geometric mean is influenced less by high values than is the arithmetic mean. Geometric means were calculated by taking the log of each concentration and then computing the weighted mean of those log-transformed values using SUDAAN software. Ninety-five percent confidence intervals around this weighted mean were calculated by adding and subtracting an amount equal to the product of a Student's t-statistic and the standard error of the weighted mean estimate. The degrees of freedom of the t-statistic were determined by subtracting the number of strata from the number of primary sampling units (PSUs) according to the data available from the complex survey design. The standard error was computed with SUDAAN's Proc Descript (design=WR), which uses Taylor series linearization for variance estimation. The weighted geometric mean and its confidence limits were then obtained by taking the antilogs of this weighted mean and its upper and lower confidence limits.

Limit of detection: The limit of detection (LOD) is the level at which the measurement has a 95% probability of being greater than zero (Taylor, 1987). The LODs for each chemical and survey period are provided in each data table and collectively in Appendix D. Concentrations less than the LOD were assigned a value equal to the LOD divided by the square root of 2 for calculation of geometric means. Assigning a value of the LOD divided by 2 made little difference in geometric mean estimates. If the proportion of results below the LOD was greater than 40%, geometric means were not calculated. For the same chemical, LOD values may change over time as a result of improvements to analytical methods. One possible consequence is that results may be reported as "< LOD" in the 1999-2000 data but be reported as a concentration value above the LOD in 2001-2002 or 2003-2004 because the analytical method had improved. Thus, for proper interpretation of LODs in the data tables, care must be taken to use the LOD that applies to the survey period. Percentile estimates (see below) that are less than the LOD for the chemical analysis are reported as "< LOD."

For most chemicals, the LOD is constant for each individual specimen analyzed. For dioxins, furans, PCBs, organochlorine pesticides, and a few other pesticides, each individual sample has its own LOD. These analyses have an individual LOD for each sample, mostly because the sample volume used for analysis differed for each sample. A higher sample volume results in a lower LOD (i.e., a better ability to detect low levels). For these chemicals, the maximum LOD value is provided in each data table and in Appendix D. The maximum LOD was the highest LOD among all the individual samples analyzed — typically, the mean LOD was about 40-50% of the maximum LOD. The same procedure for imputing values below the LOD in calculations of geometric means was used for chemicals with individual LODs for each sample. That is, concentrations less than the individual LOD were assigned a value equal to the individual LOD divided by the square root of 2. For chemicals that had individual sample LODs, a conservative rule was used for reporting percentiles: if any individual sample LOD in the demographic group was above the percentile estimate, the percentile estimate was not reported.

For chemicals measured in urine, separate tables are presented for the chemical concentration expressed per volume of urine (uncorrected table) and the chemical concentration expressed per gram of creatinine (creatinine corrected table). Geometric mean and percentile calculations were performed separately for each of these concentrations. LOD calculations were performed using the chemical concentration expressed per volume of urine, because this concentration determines the analytical sensitivity. For this reason, LOD results for urine measurements in each data table and in Appendix D are in units of weight per volume of urine. In the creatinine corrected tables, a result for a geometric mean or percentile was reported as < LOD if the corresponding geometric mean or percentile was < LOD in the table using weight per volume of urine. For example, if the 50th percentile for males was < LOD in the table using weight per volume of urine, it would also be < LOD in the creatinine corrected table.

For chemicals measured in serum lipid, separate tables are presented for the chemical concentration expressed per volume of serum (lipid unadjusted table) and the chemical concentration expressed per amount of lipid (lipid adjusted table). Geometric mean and percentile calculations were performed separately for each of these concentrations. LOD calculations were performed using the chemical concentration expressed per amount of lipid, because this concentration determines the analytical sensitivity. For this reason, LOD results for chemicals measured in each data table and in Appendix D are in weight per amount of lipid. In the lipid unadjusted tables, a result for a geometric mean or percentile was reported as < LOD if the corresponding geometric mean or percentile was < LOD in the lipid adjusted table.

Percentiles: Percentiles (50^{th}, 75^{th}, 90^{th}, and 95^{th}) are given to provide additional information about the shape of the distribution. Percentile estimates and 95% confidence interval estimates that are less than the limit of detection are indicated as <LOD in the data tables. In the *Third National Report on Human Exposure to Environmental Chemicals,* weighted percentile estimates for 1999-2000 and 2001-2002 data were calculated using SAS Proc Univariate and a proportions estimation procedure. A percentile estimate may fall on a value that is repeated multiple times in a particular demographic group defined by age, sex and race (e.g., in non-Hispanic white males 12-19 years old, five results that all have a value of 90.1). Since the *Third*

Report, we have improved the procedure for estimating percentiles to better handle this situation. This improved procedure makes each repeated value unique by adding a unique negligibly small number to each repeated value. All data from 1999-2004 have been reanalyzed using this new procedure to handle situations where the percentile falls on a repeating value. Therefore, occasional percentile estimates may differ slightly in the current *Fourth Report* than in the *Third Report*. Appendix A gives the details of the new procedure for estimating percentiles.

Taylor JK. Quality Assurance of Chemical Measurements. Lewis Publishers, Boca Raton (FL), 1987.

Interpretation of *Report* Data: Important Factors

Research studies, separate from the *Report*, are required for determining whether blood or urine levels are safe or are associated with disease or adverse effects.

The measurement of an environmental chemical in a person's blood or urine does not by itself mean that the chemical causes disease. Advances in analytical methods allow us to measure low levels of environmental chemicals in people, but separate studies of varying exposure levels and health effects are needed to determine whether such blood or urine levels result in disease. These studies must also consider other factors such as duration of exposure. The *Fourth Report* does not present new data on health risks from different exposures.

For some environmental chemicals, such as lead, research studies have given us a good understanding of the health risks associated with different blood lead levels. However, for many environmental chemicals, we need more research to assess health risks from different blood or urine levels. The results shown in the *Fourth Report* should help prioritize and foster research on human health risks that result from exposure to environmental chemicals. For more information about exposure to environmental chemicals, see the section later in this *Report* titled "Chemical and Toxicological Information", which includes Internet reference sites.

Persistent and nonpersistent chemicals; use of percentiles; comparison of levels between groups

In this *Report*, except for some metals, most measurements in urine quantify chemical metabolites of nonpersistent chemicals (those that do not stay in the body a long time). Persistent chemicals (those that stay in the body for a long time) are usually measured in serum as the parent chemical.

The higher percentiles (75^{th}, 90^{th}, 95^{th}) provided for each chemical convey useful information about the upper distribution and range of levels in the population. The 95^{th} percentile is helpful for determining whether levels observed in separate public health investigations or other studies are unusual.

Levels of chemicals are provided for the demographic groups as stratified by age, gender, and race/ethnicity. Demographic groups may not be equal in their composition with respect to other variables. CDC scientists publish separate scientific papers that make detailed comparisons of levels of chemicals in different demographic groups. See http://www.cdc.gov/exposurereport/ for a list of these papers.

Not all the chemicals in the *Report* are measured in the same individuals. Therefore, it is not possible to determine the fraction of all measured chemicals that were found at detectable levels in a given person.

Blood, serum, and urine levels of a chemical should not be confused with levels of the chemical in air, water, food, soil, or dust.

Concentrations of environmental chemicals in blood or urine are not the same as those in air, water, food, soil, or dust. For example, a chemical concentration of 10 µg/L in water does not produce a level of 10 µg/L in blood or urine. Blood or urine levels may reflect exposure from one or more sources, including air, water, food, soil, and dust.

Levels of a chemical in blood, serum, and urine are determined by how much of the chemical has entered the body through all routes of exposure, including ingestion, inhalation, and dermal absorption, and how the chemical is distributed in body tissues, transformed into metabolites, and eliminated from the body. Although the levels in the blood, serum and urine are measures of the amount of a chemical that has entered the body by all routes of exposure, the blood or urine level alone does not determine which exposure source or which route of exposure has occurred.

Chemical and Toxicological Information

The *Fourth Report* presents biomonitoring data on the exposure of the U.S. population to environmental chemicals. The measurement of an environmental chemical in a person's blood or urine does not by itself mean that the chemical causes disease or adverse effects. Advances in analytical methods allow us to measure increasingly lower levels of environmental chemicals in people. Separate studies of varying exposure levels and health effects associated with these levels are required to determine whether blood, serum, and urine levels result in disease or adverse effects. The data and information in the *Fourth Report* do not establish health effects, nor do they create guidelines.

The *Fourth Report* provides descriptive information about each chemical or chemical group including uses, sources, and pathways of human exposure; disposition within the body; effects in animals or humans; and comparative blood or urine levels from other studies. The information in the text is provided as an overview, and it is not intended as a comprehensive review of each chemical. Generally, the information was compiled from many publicly available sources, including documents from national and international agencies and organizations, peer-reviewed scientific papers obtained from electronic searches, and public government documents. Statements are based on common general information, consensus agreement among experts, or concordance among multiple scientific papers and sources. Examples of common institutional sources of information include the Agency for Toxic Substances and Disease Registry, the U.S. Environmental Protection Agency, and the agencies of the World Health Organization.

If available, generally recognized guidelines for blood or urine levels are presented in the text. For most chemicals in this *Report*, such guidelines are not available. Some guidelines are from federal agencies. One exception is the American Conference of Governmental Industrial Hygienists (ACGIH), a private organization that publishes biological exposure indices (BEIs) that "generally indicate a concentration below which nearly all workers may be repeatedly exposed without adverse health effects" (ACGIH, 2007). BEIs can be the blood or urine levels of a chemical that correspond to air-exposure limits for workers set by ACGIH. This organization notes that these values are for workers and that it is not appropriate to apply them to the general population. Information about the BEI level is provided here for comparison, not to imply that the BEI is a safety level for general population exposure.

American Conference of Government Industrial Hygienists (ACGIH). 2007 TLVs and BEIs. Cincinnati (OH). Signature Publications. 2007.

Where can I find more information?

For more information about environmental chemicals, refer to the list of web links below and the references given in the text. Links to nonfederal organizations are provided solely as a service to our readers. These links do not constitute an endorsement of these organizations or their programs by CDC or the federal government. CDC is not responsible for the content of an individual organization's Web pages found at these links.

U.S. Governmental Sources

Centers for Disease Control and Prevention (CDC) Resources:

- National Center for Health Statistics (NCHS) (http://www.cdc.gov/nchs)
  - National Health and Nutrition Examination Survey (NHANES) (http://www.cdc.gov/nchs/nhanes.htm)
- National Institute for Occupational Safety and Health (NIOSH)
  - Databases and Information Resources (http://www.cdc.gov/niosh/database.html)
  - Registry of Toxic Effects of Chemical Substances (RTECS) (http://www.cdc.gov/niosh/rtecs)

Agency for Toxic Substances and Disease Registry (ATSDR)

- Toxicological Profiles and ToxFAQs (http://www.atsdr.cdc.gov/toxpro2.html)
- Toxic Substances Portal (http://www.atsdr.cdc.gov/substances/index.asp)

U.S. Food and Drug Administration (FDA)

- Center for Food Safety and Applied Nutrition (http://www.cfsan.fda.gov)
- National Center for Toxicological Research (http://www.fda.gov/nctr)

U.S. Environmental Protection Agency (EPA)

- Integrated Risk-Information System (IRIS) (http://www.epa.gov/iris)
- Office of Prevention, Pesticides, and Toxic Substances (OPPTS) (http://www.epa.gov/opptsmnt/index.htm)

U.S. Geological Survey (USGS)

- (http://www/usgs.gov)

U.S. Department of Agriculture (USDA)

- Food Safety and Inspection Service (http://www.fsis.usda.gov)

National Institutes of Health (NIH)

- National Institute for Environmental Health Sciences (NIEHS) (http://www.niehs.nih.gov)
- National Toxicology Program (NTP) (http://ntp.niehs.nih.gov)
- National Library of Medicine (NLM), Toxicology Data Network (http://toxnet.nlm.nih.gov)

Professional and Academic Organizations

American Conference of Governmental Industrial Hygienists (http://www.acgih.org/home.htm)

Association of Public Health Laboratories (http://www.aphl.org)

International Occupational Safety and Health Information Center

- International Chemical Safety Cards (http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/index.htm)

The EXtension TOXicology NETwork (EXTOXNET)

- Pesticide Information Profiles (http://extoxnet.orst.edu/pips/ghindex.html)

World Health Organization

International Programme on Chemical Safety (IPCS) (http://www.who.int/pcs)

- Monographs of the Joint FAO/WHO Meeting on Pesticide Residues (http://www.inchem.org/pages/jmpr.html)

International Agency for Research on Cancer (IARC) (www.iarc.fr)

- Monographs on the Evaluation of Carcinogenic Risks to Humans (http://monographs.iarc.fr/ENG/Monographs/allmonos90.php)

Acrylamide

CAS No. 79-06-1

General Information

Acrylamide is a small organic molecule existing as a white crystalline powder in its pure state. Commercially, acrylamide is synthesized and used in the production of polyacrylamide polymer, gels, and binding agents. Polyacrylamides are useful water-compatible polymers used in water treatment, mineral processing, pulp and paper production, and in the synthesis or compounding of dye materials, soil conditioners, and cosmetics (NTP-CERHR, 2005). Smaller scale applications of polyacrylamides include additives to paperboard used for food packaging, in permanent press fabrics, in some sealing grouts, as an absorbent in disposable diapers, and in some cosmetics. In 1997, 217 million pounds of acrylamide were produced commercially in the U.S. (NTP-CERHR, 2005). Since acrylamide has limited volatility and high water solubility, environmental releases of acrylamide can enter aquatic systems and soils where it degrades within days and does not bioaccumulate (U.S. EPA, 1994). Recently, it was discovered that acrylamide is formed when starch-rich foods, such as potatoes and some grains, are heated at temperatures used for frying and baking. Natural substances in the food are converted to acrylamide. Foods such as french fries and potato chips can contain acrylamide at levels up to 100 times greater than levels found in cooked fish or poultry (DiNovi and Howard, 2004; FAO/WHO, 2005; FDA, 2006; Tareke et al., 2002).

People may be exposed to acrylamide from foods, smoking, drinking water, and from dermal contact with products that contain residual acrylamide. In the general population, the main source of exposure is from the diet, and an average daily intake is estimated as 0.3-2.0 µg/kg for adults (FAO/WHO, 2005), although additional exposures from cosmetic products could add a similar amount (NTP-CERHR, 2005). Estimated intakes in children are about twice that of adults (DiNovi and Howard, 2004). These estimated intakes are hundreds of times lower than occupational exposures, and well below doses known to cause nerve damage or carcinogenicity in animals, but are generally above the U.S. EPA reference dose of 0.2 µg/kg/day (U.S. EPA, 2006). Animal studies indicate that acrylamide is well absorbed, widely distributed in tissues, and is either metabolized to the reactive epoxide, glycidamide, or to glutathione conjugates (Calleman et al., 1990; Fennell et al., 2005). Elimination occurs mainly in the urine as mercapturic acid conjugates. Acrylamide is not thought to accumulate in the body at environmental doses, but can covalently bind to form adducts with proteins.

In humans, acrylamide has produced upper airway irritation following inhalation of high levels, ocular and dermal irritation from direct contact with acrylamide containing materials, and peripheral neuropathy following chronic

Acrylamide

Geometric mean and selected percentiles of hemoglobin adduct concentrations (in pmol/g hemoglobin) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**61.2** (58.1-64.4)	**54.8** (52.8-57.7)	**79.1** (73.5-85.6)	**141** (124-155)	**192** (168-217)	7101
Age group							
3-5 years	03-04	**59.4** (53.6-65.7)	**58.6** (51.7-64.9)	**75.7** (63.4-83.6)	**90.6** (81.9-105)	**108** (86.2-118)	350
6-11 years	03-04	**58.6** (56.1-61.2)	**57.3** (55.2-59.7)	**71.0** (67.4-76.3)	**86.8** (81.2-91.4)	**98.8** (91.0-104)	769
12-19 years	03-04	**57.4** (54.4-60.5)	**54.5** (52.1-57.4)	**70.7** (65.6-75.7)	**100** (89.2-114)	**132** (115-151)	1889
20-59 years	03-04	**66.2** (62.2-70.6)	**57.9** (54.6-61.1)	**96.1** (83.6-108)	**163** (147-191)	**223** (194-243)	2570
60 years and older	03-04	**50.1** (47.9-52.3)	**46.5** (44.0-49.2)	**61.0** (57.6-66.0)	**96.1** (88.0-108)	**141** (120-152)	1523
Gender							
Males	03-04	**63.9** (60.2-67.9)	**57.0** (53.7-60.1)	**85.5** (79.2-93.7)	**152** (139-175)	**220** (189-237)	3509
Females	03-04	**58.7** (55.9-61.5)	**53.4** (51.8-55.9)	**73.9** (69.5-80.6)	**126** (111-142)	**164** (147-191)	3592
Race/ethnicity							
Mexican Americans	03-04	**61.7** (58.7-64.9)	**57.4** (54.4-60.4)	**73.0** (69.2-77.3)	**101** (95.0-115)	**149** (125-179)	1792
Non-Hispanic blacks	03-04	**63.8** (57.3-71.1)	**57.1** (52.1-64.1)	**86.5** (74.6-104)	**156** (120-203)	**218** (172-271)	1874
Non-Hispanic whites	03-04	**62.4** (59.0-66.0)	**55.3** (53.0-58.6)	**82.2** (75.4-89.1)	**146** (129-163)	**197** (172-223)	2994

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 3.0.

occupational exposures. Axonal degeneration, presynaptic nerve terminal binding (LoPachin, 2005), and neuronal DNA reactivity (Doerge et al., 2005) have been demonstrated in animals. Animal studies have shown that acrylamide can cause nerve damage (neuropathy), reproductive effects (reduced litter size, fetal death, male germinal cell injury, dominant lethality), and cancer (mammary, adrenal, thyroid, scrotal, uterine, and other sites) (FAO/WHO, 2005; NTP-CERHR, 2005, Rice, 2005; U.S. EPA, 2006). Glycidamide has been shown to react with DNA (Doerge et al., 2005; Klaunig et al., 2005; Maniere et al., 2005; Puppel et al., 2005), to increase the unscheduled synthesis of DNA in tumor susceptible tissues (Klaunig et al., 2005), and to increase DNA reactivity when glutathione availability is reduced (Klaunig et al., 2005; Puppel et al., 2005). In addition, altered gene expression in testicular tissues (Yang et al., 2005) and sperm DNA adducts (Xie et al., 2006) have been demonstrated after acrylamide dosing. Acrylamide is clastogenic and can produce dominant lethal mutations, probably through its epoxide metabolite, glycidamide (NTP-CERHR, 2005; U.S. EPA, 2006). IARC classifies acrylamide as probably carcinogenic to humans. Additional information is available from U.S. EPA at: http://www.epa.gov/iris/ and from the Food and Agriculture Organization of the United Nations and WHO at: http://www.who.int/ipcs/food/jecfa/summaries/summary_report_64_final.pdf.

Biomonitoring Information

Acrylamide and glycidamide hemoglobin adducts (AHA and GHA, respectively) are markers of integrated acrylamide exposure over the preceding few months. Adducts are formed when either acrylamide or glycidamide react to form a permanent covalent bond with hemoglobin in the blood. After exposure ceases, levels of AHA adducts decline but may remain detectable for several months (Hagmar et al., 2001). AHA levels have been shown to increase with dietary intake (Hagmar et al., 2005, Vesper 2005) and smoking (Bergmark, 1997; Schettgen et al., 2002, 2004).

Levels of AHA and GHA reported the NHANES 2003-2004 sample are generally similar to those seen in several previous studies of non-occupationally exposed subjects (Bergmark et al., 1997; Hagmar et al., 2005; Schettgen et al., 2002, 2003, 2004; Vesper et al., 2006, 2008), although different analytic methods can affect results. Several of these studies have shown that smokers have adduct levels that are three to fourfold higher than non-smokers; most non-smokers had levels less than about 100 pmol/gram hemoglobin. The degree of formation of the more toxic glycidamide and levels of GHA can be influenced by polymorphisms in several of the enzymes that metabolize acrylamide (Duale et al., 2009). Younger children may have slightly higher levels possibly due to increased intake of acrylamide-containing foods relative to body size (Dybing et al., 2005, Mucci et al., 2008).

Glycidamide

Geometric mean and selected percentiles of hemoglobin adduct concentrations (in pmol/g hemoglobin) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**59.3** (56.7-62.1)	**59.9** (57.6-62.5)	**85.9** (81.6-90.5)	**130** (120-141)	**167** (153-181)	
Age group							
3-5 years	03-04	**71.6** (66.9-76.7)	**71.1** (66.9-78.9)	**94.7** (87.3-101)	**118** (103-126)	**126** (119-135)	
6-11 years	03-04	**74.1** (70.3-78.2)	**75.0** (70.9-77.9)	**95.6** (90.4-103)	**121** (112-134)	**141** (126-157)	
12-19 years	03-04	**55.4** (51.1-60.1)	**59.2** (56.1-62.1)	**79.2** (72.7-86.7)	**113** (94.9-138)	**146** (123-169)	
20-59 years	03-04	**62.5** (59.4-65.8)	**60.9** (58.7-64.4)	**90.7** (84.4-98.2)	**143** (130-159)	**187** (169-204)	
60 years and older	03-04	**45.5** (42.8-48.3)	**46.8** (44.8-49.3)	**65.2** (63.5-66.9)	**96.4** (90.0-103)	**129** (111-141)	
Gender							
Males	03-04	**59.5** (56.9-62.3)	**59.4** (56.8-61.8)	**87.1** (82.5-92.3)	**136** (123-148)	**174** (157-197)	
Females	03-04	**59.1** (56.0-62.5)	**60.4** (57.5-64.0)	**85.0** (80.2-90.0)	**125** (116-135)	**159** (143-175)	
Race/ethnicity							
Mexican Americans	03-04	**64.7** (61.2-68.4)	**65.4** (61.1-70.1)	**87.4** (81.5-94.4)	**118** (110-129)	**152** (135-170)	
Non-Hispanic blacks	03-04	**53.8** (51.1-56.7)	**56.0** (52.4-59.7)	**83.0** (75.2-91.5)	**121** (108-140)	**159** (129-204)	
Non-Hispanic whites	03-04	**61.1** (57.6-64.9)	**60.7** (57.9-64.2)	**87.5** (83.0-93.5)	**136** (124-149)	**172** (157-194)	

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 4.0.

In occupational settings, AHA levels were several fold to several hundredfold higher than levels in non-exposed non-smokers (Bergmark et al., 1993; Hagmar et al., 2001; Perez et al., 1999). AHA levels correlated with a neurologic symptom index and specific physiologic measures in an occupational setting and correlated better with clinical signs and symptoms than urinary excretion of the mercapturic acid metabolite (Calleman et al., 1994). In another study, symptoms of numbness or tingling in the extremities did not occur in exposed workers whose AHA levels were below 510 pmol/gram hemoglobin, and 39% of workers with levels above 1000 pmol/gram hemoglobin had these symptoms (Hagmar et al., 2001).

Finding a measurable amount of acrylamide or glycidamide hemoglobin adducts in blood does not mean that these levels of acrylamide or glycidamide hemoglobin adducts cause adverse health effects. Biomonitoring studies of acrylamide or glycidamide hemoglobin adducts provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of acrylamide than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Cotinine

CAS No. 486-56-6

Metabolite of nicotine (a component of tobacco smoke)

General Information

Tobacco use is the most important preventable cause of premature morbidity and mortality in the United States. The consequences of smoking and of using smokeless tobacco products are well known and include an increased risk for several types of cancer, emphysema, acute respiratory illness, cardiovascular disease, stroke, and various other disorders (U.S. DHHS, 2006). Persons exposed to secondhand tobacco smoke (environmental tobacco smoke [ETS]) may have adverse health effects that include lung cancer and coronary heart disease; maternal exposure during pregnancy can result in lower birth weight. Children exposed to ETS are at increased risk for sudden infant death syndrome, acute respiratory infections, ear problems, and exacerbated asthma (U.S. DHHS, 2004). The smoke produced by burning tobacco contains at least 250 chemicals that are toxic or carcinogenic, and more than 50 compounds present in ETS are known or reasonably anticipated to be human carcinogens (NTP, 2004).

Cigarettes contain about 1.5% nicotine by weight (Kozlowski et al., 1998), producing roughly 1–2 mg of bioavailable nicotine per cigarette (Benowitz and Jacob,

Serum Cotinine

Metabolite of nicotine (component of tobacco smoke)

Geometric mean and selected percentiles of serum concentrations (in ng/mL) for the **non-smoking** U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.060** (<LOD-.080)	**.240** (.190-.302)	**1.02** (.770-1.28)	**1.96** (1.60-2.62)	5999
	01-02**	**.062** (.050-.077)	**< LOD**	**.160** (.120-.220)	**.930** (.740-1.17)	**2.20** (1.83-2.44)	6819
	03-04	**.071** (.057-.089)	**.050** (.040-.070)	**.210** (.140-.310)	**.990** (.740-1.30)	**2.17** (1.81-2.54)	6320
Age group							
3-11 years	99-00	**.164** (.115-.234)	**.110** (.066-.188)	**.500** (.260-1.16)	**1.88** (.997-3.44)	**3.44** (1.42-4.79)	1174
	01-02**	**.110** (.076-.160)	**.070** (<LOD-.130)	**.570** (.310-1.00)	**2.23** (1.63-2.78)	**3.23** (2.53-4.01)	1415
	03-04	**.137** (.088-.213)	**.120** (.060-.220)	**.620** (.310-1.20)	**2.04** (1.38-2.94)	**3.35** (2.12-4.68)	1252
12-19 years	99-00	**.163** (.142-.187)	**.110** (.080-.163)	**.540** (.428-.660)	**1.66** (1.50-1.95)	**2.62** (2.09-3.39)	1773
	01-02**	**.086** (.059-.126)	**.050** (<LOD-.110)	**.350** (.190-.580)	**1.53** (1.09-2.12)	**3.12** (2.47-3.99)	1902
	03-04	**.110** (.087-.139)	**.080** (.060-.120)	**.510** (.350-.670)	**1.55** (1.21-1.93)	**2.68** (1.96-4.02)	1783
20 years and older	99-00	*	**.050** (<LOD-.061)	**.167** (.140-.193)	**.630** (.533-.820)	**1.50** (1.28-1.66)	3052
	01-02**	**.052** (<LOD-.063)	**< LOD**	**.110** (.090-.150)	**.630** (.470-.790)	**1.42** (1.14-1.89)	3502
	03-04	**.058** (.047-.071)	**.040** (.030-.050)	**.140** (.100-.200)	**.630** (.480-.840)	**1.54** (1.26-1.92)	3285
Gender							
Males	99-00	**.124** (.106-.145)	**.080** (.060-.110)	**.308** (.220-.410)	**1.20** (.950-1.49)	**2.39** (1.66-3.22)	2789
	01-02**	**.075** (.059-.094)	**.050** (<LOD-.070)	**.230** (.160-.320)	**1.17** (.960-1.49)	**2.44** (2.23-2.99)	3152
	03-04	**.087** (.070-.108)	**.060** (.040-.080)	**.280** (.190-.360)	**1.23** (.910-1.68)	**2.63** (2.09-3.19)	2937
Females	99-00	*	**< LOD**	**.180** (.148-.230)	**.850** (.600-1.14)	**1.85** (1.33-2.45)	3210
	01-02**	**.053** (<LOD-.066)	**< LOD**	**.120** (.090-.180)	**.710** (.540-.990)	**1.77** (1.32-2.20)	3667
	03-04	**.060** (.047-.077)	**.040** (.030-.060)	**.160** (.110-.260)	**.860** (.580-1.15)	**1.76** (1.32-2.22)	3383
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**.140** (.110-.180)	**.506** (.370-.726)	**1.21** (.900-1.70)	2241
	01-02**	**.060** (<LOD-.084)	**< LOD**	**.160** (.080-.310)	**.730** (.480-1.19)	**2.12** (1.19-2.96)	1878
	03-04	**.054** (.043-.068)	**.030** (.020-.050)	**.120** (.080-.180)	**.690** (.430-1.00)	**2.65** (1.87-3.57)	1707
Non-Hispanic blacks	99-00	**.175** (.153-.201)	**.131** (.111-.150)	**.505** (.400-.625)	**1.43** (1.21-1.75)	**2.34** (1.84-3.50)	1333
	01-02**	**.164** (.137-.197)	**.130** (.110-.160)	**.580** (.450-.770)	**1.77** (1.55-2.05)	**3.15** (2.50-4.30)	1602
	03-04	**.144** (.104-.198)	**.120** (.080-.180)	**.520** (.350-.770)	**1.54** (1.20-2.14)	**2.77** (2.18-3.54)	1704
Non-Hispanic whites	99-00	*	**.050** (<LOD-.073)	**.216** (.154-.312)	**.950** (.621-1.40)	**1.92** (1.48-3.02)	1950
	01-02**	**.052** (<LOD-.068)	**< LOD**	**.120** (.090-.180)	**.800** (.570-1.11)	**1.88** (1.48-2.30)	2847
	03-04	**.066** (.050-.087)	**.040** (.030-.070)	**.180** (.120-.300)	**.920** (.620-1.32)	**2.01** (1.70-2.49)	2500

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, and 03-04 are 0.05, and 0.015, respectively.
** In the 2001-2002 survey period, 83% of measurements had an LOD of 0.015 ng/mL, and 17% had an LOD of 0.05 ng/mL.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

1994; Hukkanen et al., 2005). Inhaling tobacco smoke from either active or passive (ETS) smoking is the main source of nicotine exposure for the general population. Up to 90% of the nicotine delivered in tobacco smoke is absorbed rapidly from the lungs into the blood stream (Armitage et al., 1975; Iwase et al., 1991). Mean air concentrations of nicotine in public spaces where smoking is allowed range from 0.3 to 30 µg/m^3, with higher levels measured in restaurants and bars. In homes with one or more smokers, mean air concentrations typically range from 2 to 14 µg/m^3 (NTP, 2004). For an adult, the primary sources for ETS exposure are in a workplace where smoking occurs and in a residence shared with one or more smokers. Children are primarily exposed to ETS by parents and caregivers who smoke.

Nicotine can also be absorbed from the gastrointestinal tract and skin by using snuff, chewing tobacco, or chewing gum, nasal sprays, or skin patches that contain nicotine. Workers who harvest tobacco can be exposed to nicotine and become intoxicated as a result of the transdermal absorption of nicotine contained in the plant. The tobacco plant, *Nicotiana tabacum*, contains nicotine in larger amounts than other nicotine-containing plants, which include potatoes, tomatoes, eggplants, and peppers. Nicotine is also used commercially as an insecticide in its sulfate and alkaloid forms.

Once absorbed, nicotine has a half-life in blood plasma of several hours (Benowitz, 1996). Cotinine, the primary metabolite of nicotine, is currently regarded as the best biomarker in active smokers and in nonsmokers exposed to ETS. Measuring cotinine is preferred over measuring nicotine because cotinine persists longer in the body with a plasma half-life of about 16 hours (Benowitz and Jacob, 1994). However, non-Hispanic blacks metabolize cotinine more slowly than do non-Hispanic whites (Benowitz et al., 1999; Perez-Stable et al., 1998). Cotinine can be measured in serum, urine, saliva, and hair. Nonsmokers exposed to typical levels of ETS have serum cotinine levels of less than 1 ng/mL, with heavy exposure to ETS producing levels in the 1–10 ng/mL range. Active smokers almost always have levels higher than 10 ng/mL and sometimes higher than 500 ng/mL (Hukkanen et al., 2005).

Nicotine stimulates preganglionic cholinergic receptors within peripheral sympathetic autonomic ganglia and at cholinergic sites within the central nervous system. Acute tobacco or nicotine intoxication can produce dizziness, nausea, vomiting, diaphoresis, salivation, diarrhea, variable changes in blood pressure and heart rate, seizures, and death. Nicotine also indirectly causes a release of dopamine in the brain regions that control pleasure and motivation, a process involved in the development of addiction. Symptoms of nicotine withdrawal include irritability, craving, cognitive and sleep disturbances, and increased appetite.

The IARC and the NTP consider tobacco smoke to be a human carcinogen. NIOSH guidelines consider ETS to be a potential occupational carcinogen and recommend that exposure be reduced to the lowest feasible concentration. The Federal Aviation Administration has banned the smoking of tobacco products on both domestic and foreign air carrier flights in the United States. More information about the effects of smoking and nicotine can be found at: http://www.nida.nih.gov/researchreports/nicotine/nicotine.html.

Biomonitoring Information

Serum cotinine levels reflect recent exposure to nicotine in tobacco smoke. Nonsmoking is usually defined as a serum cotinine level of less than or equal to 10 ng/mL (Pirkle et al., 1996).

The serum cotinine levels seen in the NHANES 2003-2004 appear approximately similar to levels seen in the previous survey period (NHANES 2001-2002) for the total population estimates. Serum cotinine has been measured in many studies of nonsmoking populations, with levels showing similar or slightly higher results (depending on the degree of ETS exposure) than those reported in the previous NHANES (CDC 2005; NCI, 1999). Over the previous decade, levels of exposure to ETS appeared to decrease since geometric mean cotinine serum concentrations in nonsmokers had fallen by approximately 70% and the rate of detectable cotinine in nonsmokers fell from 88% to 43% when NHANES 1988–1991 was compared to NHANES 1999–2002, (CDC, 2005; Pirkle et al., 2006). The overall decline in population estimates of serum cotinine likely reflects decreased ETS exposure among nonsmokers in locations with smoke-free laws (Pickett et al., 2006; Soliman et al., 2004). During each previous NHANES survey, the adjusted geometric mean serum cotinine was higher in children (aged 4–11 years) than in adults among both non-Hispanic blacks and non-Hispanic whites (Pirkle et al., 2006). Non-Hispanic blacks had higher serum cotinine concentrations compared with either non-Hispanic whites or Mexican-Americans. Higher levels of cotinine have previously been reported for non-Hispanic black smokers (Caraballo et al., 1998). Differences in cotinine concentrations among race/ethnicity and age groups may be influenced by pharmacokinetic differences as well as by ETS exposure (Benowitz et al., 1999; Hukkanen et al., 2005; Wilson et al., 2005).

Biomonitoring studies of serum cotinine will help physicians and public health officials determine whether people have been exposed to higher levels of ETS than are found in the general population. Biomonitoring data can also help scientists plan and conduct research about exposure to ETS and about its health effects.

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N,N-Diethyl-*meta*-toluamide (DEET)

CAS No. 134-62-3

General Information

N,N-diethyl-*meta*-toluamide (DEET) is an insect repellent that was first marketed in 1957. DEET can be applied to clothing and the skin to repel biting insects. Its use is recommended for prevention of several vector-borne diseases. There are over 225 insect repellents brands containing DEET, and they range in concentration from 4% to 100%. DEET is also used in combination with dermal sun screens (U.S.EPA, 1998). DEET is not registered for use on agricultural commodities. One survey detected DEET in 74% of sampled streams in the U.S. (Kolpin et al., 2002).

General population exposure to DEET occurs from skin application and from inhalation of aerosol formulations. Exposure can also occur from consuming food contaminated by DEET on hands or that was sprayed nearby. About 3-8% of dermally applied DEET is absorbed, but higher DEET concentrations and different formulations may result in greater absorption (Sudakin and Trevathan, 2003). After absorption, DEET is metabolized via hydroxylation and dealkylation pathways and eliminated in the urine within approximately 24 hours (Selim et al., 1995; Sudakin and Trevathan, 2003). People in outdoor occupations may apply DEET more frequently or use higher concentration formulations resulting in higher levels of exposure.

Human health effects from DEET at low environmental doses or at biomonitored levels from low environmental exposures are unknown. DEET has low acute toxicity. Most reports of adverse effects from overexposure to DEET involve skin reactions (Bell et al., 2002). Neurological effects in humans, including seizures and encephalopathy, have been reported as result of self-poisoning by ingestion or excessive dermal application, (U.S. EPA, 1998). DEET is not a developmental or reproductive toxicant in animals (U.S.EPA, 2005). DEET is not genotoxic, and it has not been rated by IARC or NTP with respect to human carcinogenicity. Additional information is available from U.S.EPA at: http://www.epa.gov/pesticides/.

Urinary N,N-Diethyl-*meta*-toluamide (DEET)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1977
	01-02	*	< LOD	< LOD	.110 (.100-.140)	.180 (.140-.220)	2535
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	480
	01-02	*	< LOD	< LOD	.130 (.100-.180)	.210 (.120-.560)	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	672
	01-02	*	< LOD	< LOD	.130 (.110-.160)	.220 (.130-.520)	829
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	825
	01-02	*	< LOD	< LOD	.110 (<LOD-.130)	.170 (.120-.210)	1126
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	964
	01-02	*	< LOD	< LOD	.110 (.100-.150)	.180 (.130-.250)	1191
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1013
	01-02	*	< LOD	< LOD	.110 (.100-.130)	.170 (.130-.210)	1344
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	688
	01-02	*	< LOD	< LOD	.110 (<LOD-.140)	.130 (.110-.190)	678
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	518
	01-02	*	< LOD	< LOD	.100 (<LOD-.140)	.140 (.100-.240)	700
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	598
	01-02	*	< LOD	< LOD	.110 (.100-.140)	.180 (.130-.270)	956

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.449 and 0.1.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

Urinary levels of DEET reflect recent exposure. Urinary levels of DEET were characterized only at the 90th and 95th percentiles of the U.S. representative subsamples from NHANES 2001-2002. In this survey period, the limit of detection was lower than for the NHANES 1999-2000 survey period (CDC, 2005). DEET was detected in 10% of 60 Latino children in eastern North Carolina farm worker households (Arcury et al., 2007). Urinary DEET levels as high as 5,690 µg/L were measured in eight park employees who applied 71% DEET once a day (Smallwood et al., 1992).

Finding a measurable amount of DEET in urine does not mean that the level of DEET causes an adverse health effect. Biomonitoring studies on levels of DEET provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DEET than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary N,N-Diethyl-*meta*-toluamide (DEET) (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1977
	01-02	*	< LOD	< LOD	.270 (.240-.300)	.410 (.350-.500)	2534
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	480
	01-02	*	< LOD	< LOD	.330 (.230-.630)	.640 (.280-1.93)	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	672
	01-02	*	< LOD	< LOD	.190 (.150-.240)	.250 (.190-.490)	828
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	825
	01-02	*	< LOD	< LOD	.270 (<LOD-.320)	.410 (.370-.500)	1126
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	964
	01-02	*	< LOD	< LOD	.200 (.170-.250)	.320 (.250-.440)	1191
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1013
	01-02	*	< LOD	< LOD	.330 (.290-.370)	.500 (.410-.580)	1343
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	688
	01-02	*	< LOD	< LOD	.190 (<LOD-.230)	.280 (.230-.350)	678
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	518
	01-02	*	< LOD	< LOD	.130 (<LOD-.150)	.190 (.140-.270)	699
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	598
	01-02	*	< LOD	< LOD	.300 (.270-.350)	.480 (.390-.550)	956

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Disinfection By-Products (Trihalomethanes)

Bromodichloromethane CAS No. 75-27-4

Dibromochloromethane (Chlorodibromomethane) CAS No. 124-48-1

Tribromomethane (Bromoform) CAS No. 75-25-2

Trichloromethane (Chloroform) CAS No. 57-57-8

General Information

Disinfection by-products (DBP) are a class of chemical by-products also referred to as trihalomethanes (THMs), formed when chlorine or bromine interacts with the natural organic materials found in water. DBPs also include other formed products, such as haloacetic acids, haloacetonitriles, haloketones, and chlorophenols. The composition and levels of specific DBPs are determined by water quality, water treatment conditions, and disinfectant type (IPCS, 2000). Primary sources of DBPs are chlorinated drinking water and recreational water bodies, such as swimming pools.

In drinking water, trichloromethane is the predominant DBP, usually found at much higher levels than bromodichloromethane; tribromomethane is the least abundant (Krasner et al., 1989). DBPs are volatile at room temperature and can be detected in ambient air during activities such as showering, bathing, dishwashing, and swimming (Backer, et al., 2000; Gordon et al., 2006). Trichloromethane has industrial applications and is used to produce refrigerants and feedstock. It may be released into the environment where chlorine-based chemicals are used for bleaching and disinfecting processes or disposed at hazardous waste sites (IPCS, 2004; LaRegina, et al. 1986). Tribromomethane has limited industrial uses, mainly in geological assaying, electronics manufacturing, and as a solvent in laboratory analyses (ATSDR, 2005). DBPs tend not to bioaccumulate in aquatic organisms or persist in open or surface waters or soils, but they can remain in water within closed pipe systems. Workplace exposure may occur during the production of trichloromethane or tribromomethane, or in workplaces where DBPs may be generated, such as pulp or paper manufacturing, swimming pools, and water treatment plants (IPCS, 2004).

General population exposure to DBPs occurs primarily through ingesting chlorinated water and inhaling the water

Blood Bromodichloromethane

Geometric mean and selected percentiles of blood concentrations (in pg/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2.21** (1.65-2.97)	**2.30** (1.56-3.21)	**4.63** (3.24-6.20)	**8.45** (5.86-12.0)	**12.0** (7.68-19.2)	785
	03-04	**1.50** (1.20-1.86)	**1.40** (1.10-1.90)	**3.40** (2.60-4.20)	**6.20** (5.30-7.00)	**9.50** (7.00-12.0)	1322
Age group							
20-59 years	01-02	**2.21** (1.65-2.97)	**2.30** (1.56-3.21)	**4.63** (3.24-6.20)	**8.45** (5.86-12.0)	**12.0** (7.68-19.2)	785
	03-04	**1.50** (1.20-1.86)	**1.40** (1.10-1.90)	**3.40** (2.60-4.20)	**6.20** (5.30-7.00)	**9.50** (7.00-12.0)	1322
Gender							
Males	01-02	**2.19** (1.60-3.00)	**2.31** (1.63-3.21)	**4.64** (3.21-6.08)	**7.96** (5.74-15.3)	**13.0** (6.93-20.5)	382
	03-04	**1.48** (1.18-1.85)	**1.40** (.940-2.00)	**3.40** (2.60-4.30)	**6.60** (5.40-7.20)	**11.0** (7.20-14.0)	650
Females	01-02	**2.24** (1.66-3.01)	**2.28** (1.49-3.24)	**4.63** (3.09-7.01)	**8.62** (5.26-12.9)	**11.1** (7.68-25.0)	403
	03-04	**1.51** (1.21-1.90)	**1.50** (1.10-1.90)	**3.30** (2.50-4.20)	**6.10** (4.69-7.30)	**7.80** (6.40-12.0)	672
Race/ethnicity							
Mexican Americans	01-02	**3.28** (2.29-4.68)	**3.32** (2.19-4.70)	**6.81** (3.71-10.4)	**10.8** (8.24-14.7)	**14.7** (11.1-20.5)	227
	03-04	**1.65** (1.15-2.38)	**1.60** (.820-2.80)	**3.50** (2.60-4.90)	**7.30** (4.50-10.0)	**10.0** (7.30-11.0)	244
Non-Hispanic blacks	01-02	**2.32** (1.82-2.94)	**2.50** (1.56-3.55)	**4.57** (3.60-5.56)	**8.69** (5.63-9.49)	**10.0** (5.89-13.5)	130
	03-04	**1.56** (1.15-2.13)	**1.70** (1.10-2.20)	**2.90** (2.15-3.80)	**5.10** (3.80-6.60)	**6.60** (4.90-13.0)	290
Non-Hispanic whites	01-02	**2.02** (1.42-2.87)	**2.16** (1.36-3.09)	**4.34** (2.92-6.01)	**7.33** (4.72-15.3)	**11.1** (6.01-26.1)	365
	03-04	**1.42** (1.11-1.81)	**1.30** (.850-1.90)	**3.30** (2.30-4.40)	**6.20** (5.20-7.20)	**9.80** (6.70-13.0)	684

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.233 and 0.62.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.

vapor. Dermal absorption also may occur during bathing and swimming (ATSDR, 1997, 2005; Dick, et al., 1995; Leavens et al., 2007). Each of the DBPs is rapidly absorbed and distributed widely throughout the body. In animals, these chemicals undergo hepatic metabolism to reactive chemicals, which can bind to cell macromolecules and be toxic in large amounts (IPCS, 2000). Ultimately, DBPs are metabolized to carbon dioxide, which is eliminated in exhaled air within a few hours. Only a small amount of each DBP is eliminated unchanged in urine. Elimination half-lives for these chemicals are less than four hours (ATSDR, 2005; Leavens et al., 2007).

Human health effects from DBPs at low environmental doses or at biomonitored levels from low environmental exposures are unclear or unknown. Humans exposed to massive levels of trichloromethane or tribromomethane develop central nervous system depression and hepatotoxicity (ATSDR, 2005, 1997). Acute animal toxicity studies of each of these chemicals have found central nervous system depression, liver and renal damage or necrosis, and occasionally, cardiac depression and arrhythmias (IPCS, 2000). In studies of rodents chronically fed high doses of either trichloromethane or bromodichloromethane, carcinomas occurred in the liver and kidney; large intestine tumors and polyps were also noted with bromodichloromethane (NCI, 1976; NTP, 1987). Chronic feeding studies in rodents with either dibromochloromethane or tribromomethane showed inconsistent evidence of carcinogenicity across species and genders. The DBPs did not produce reproductive or developmental effects in animals unless maternal toxicity was present, but bromodichloromethane altered sperm motility (IPCS, 2000). Numerous epidemiologic studies of the relationships between chlorinated water source and various cancers, adverse reproductive outcomes, and cardiovascular disease have been inconclusive (IPCS, 2000). IARC classified trichloromethane and bromodichloromethane as possible human carcinogens, and NTP determined that these chemicals are reasonably anticipated to be human carcinogens. However, IARC found dibromochloromethane and tribromomethane to be unclassifiable regarding human carcinogenicity. The U.S. EPA has established drinking water and environmental standards for "total THMs." OSHA and ACGIH have established workplace standards and guidelines, respectively, for trichloromethane and tribromomethane. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Blood Dibromochloromethane

Geometric mean and selected percentiles of blood concentrations (in pg/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**.867** (.521-1.44)	**.780** (.340-1.90)	**2.61** (1.22-4.38)	**5.46** (3.53-9.71)	**8.96** (5.04-12.9)	781
	03-04	*	**< LOD**	**1.30** (1.00-1.80)	**3.60** (2.70-4.80)	**7.20** (4.80-8.60)	1333
Age group							
20-59 years	01-02	**.867** (.521-1.44)	**.780** (.340-1.90)	**2.61** (1.22-4.38)	**5.46** (3.53-9.71)	**8.96** (5.04-12.9)	781
	03-04	*	**< LOD**	**1.30** (1.00-1.80)	**3.60** (2.70-4.80)	**7.20** (4.80-8.60)	1333
Gender							
Males	01-02	**.850** (.481-1.50)	**.730** (.300-2.25)	**2.66** (.960-4.38)	**4.77** (3.33-9.20)	**8.06** (4.31-14.6)	371
	03-04	*	**< LOD**	**1.30** (1.00-1.90)	**3.70** (2.70-5.70)	**7.20** (5.20-8.60)	657
Females	01-02	**.884** (.550-1.42)	**.820** (.340-1.69)	**2.54** (1.37-4.31)	**6.30** (3.28-10.1)	**9.91** (5.02-13.0)	410
	03-04	*	**< LOD**	**1.30** (1.00-1.80)	**3.60** (2.50-4.80)	**6.60** (3.80-9.20)	676
Race/ethnicity							
Mexican Americans	01-02	**1.61** (.843-3.06)	**1.49** (.670-3.99)	**4.59** (1.93-8.89)	**9.26** (5.21-12.1)	**12.0** (9.63-16.1)	233
	03-04	**1.20** (.963-1.50)	**1.10** (.810-1.40)	**2.30** (1.50-4.10)	**5.20** (3.80-6.90)	**7.70** (5.20-11.0)	256
Non-Hispanic blacks	01-02	**1.03** (.505-2.09)	**.930** (.530-2.03)	**2.03** (.770-7.06)	**4.22** (2.01-10.5)	**8.09** (2.80-16.5)	128
	03-04	*	**< LOD**	**.970** (.650-1.60)	**1.90** (1.20-3.20)	**3.20** (1.80-5.20)	288
Non-Hispanic whites	01-02	**.736** (.413-1.31)	**.640** (<LOD-1.93)	**2.49** (.870-4.27)	**4.57** (3.00-7.12)	**6.98** (4.27-11.1)	357
	03-04	*	**< LOD**	**1.30** (.950-1.80)	**3.30** (2.50-4.60)	**6.60** (3.70-9.20)	685

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.271 and 0.62.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

Levels of blood DBPs reflect recent exposure. Geometric mean blood trichloromethane levels were 0.039 and 0.043 ng/mL among non-smoking and smoking adults, respectively, in a subsample of NHANES 1999-2000 participants (Lin et al., 2008), which were at least twice as high as comparable levels in NHANES 2001-2002 and 2003-2004. In a non-representative sample of NHANES III (1988-1994) participants, the geometric mean and median blood trichloromethane levels, respectively, were 0.043 and 0.023 μg/L (Churchill et al., 2001). Similar median blood trichloromethane levels were reported in smaller studies of U.S adults (Ashley et al., 2005; Backer et al., 2000; Buckley et al., 1997) and in this *Report*. Immediately following bathing or showering with chlorinated water, median blood levels of trichloromethane, dibromochloromethane, and bromodichloromethane can increase two to four times over baseline levels, and then return to baseline rapidly during the next one to two hours (Ashley et al., 2005; Backer et al., 2000).

Finding a measurable amount of one or more of these THMs in blood does not mean that the level of THMs causes an adverse health effect. Biomonitoring studies of blood THMs can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of THMs than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Blood Tribromomethane (Bromoform)

Geometric mean and selected percentiles of blood concentrations (in pg/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**1.57** (1.07-2.31)	**1.39** (.960-2.02)	**2.78** (1.76-4.63)	**6.05** (2.92-29.2)	**15.5** (3.68-85.4)	774
	03-04	*	**< LOD**	**1.80** (<LOD-2.80)	**3.74** (2.30-7.10)	**6.40** (3.60-14.0)	1310
Age group							
20-59 years	01-02	**1.57** (1.07-2.31)	**1.39** (.960-2.02)	**2.78** (1.76-4.63)	**6.05** (2.92-29.2)	**15.5** (3.68-85.4)	774
	03-04	*	**< LOD**	**1.80** (<LOD-2.80)	**3.74** (2.30-7.10)	**6.40** (3.60-14.0)	1310
Gender							
Males	01-02	**1.49** (.944-2.34)	**1.29** (.850-1.98)	**2.65** (1.49-5.05)	**6.12** (2.26-33.9)	**14.9** (2.79-69.9)	374
	03-04	*	**< LOD**	**1.90** (<LOD-2.87)	**4.00** (2.40-6.80)	**6.50** (4.00-13.0)	645
Females	01-02	**1.67** (1.17-2.39)	**1.46** (1.05-2.21)	**2.86** (1.89-4.57)	**5.69** (3.30-27.5)	**22.2** (5.09-49.6)	400
	03-04	*	**< LOD**	**1.72** (<LOD-2.65)	**3.20** (1.93-7.70)	**6.10** (3.10-31.0)	665
Race/ethnicity							
Mexican Americans	01-02	**2.34** (1.15-4.77)	**1.66** (.990-3.38)	**4.03** (1.42-36.5)	**28.3** (4.39-49.2)	**40.8** (31.5-57.9)	234
	03-04	*	**1.60** (<LOD-3.10)	**3.30** (<LOD-9.40)	**7.60** (3.60-14.0)	**11.0** (5.60-210)	242
Non-Hispanic blacks	01-02	**1.51** (.857-2.67)	**1.47** (.780-3.15)	**2.58** (1.39-4.64)	**4.34** (2.57-8.48)	**6.27** (3.28-15.2)	121
	03-04	*	**< LOD**	**1.60** (<LOD-2.30)	**2.50** (1.80-3.20)	**3.20** (2.40-6.10)	289
Non-Hispanic whites	01-02	**1.47** (.980-2.22)	**1.29** (.840-2.06)	**2.58** (1.51-4.91)	**5.69** (2.84-21.2)	**11.0** (3.30-69.9)	362
	03-04	*	**< LOD**	**1.70** (<LOD-2.90)	**3.50** (2.00-7.70)	**5.90** (3.30-21.0)	680

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.596 and 1.5.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood Trichloromethane (Chloroform)

Geometric mean and selected percentiles of blood concentrations (in pg/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**16.6** (13.0-21.1)	**16.1** (11.9-22.2)	**31.7** (23.9-40.4)	**55.5** (44.5-68.6)	**72.1** (57.3-105)	744
	03-04	**10.2** (8.56-12.2)	**10.0** (8.50-13.0)	**20.0** (17.0-24.0)	**35.0** (29.0-40.0)	**50.0** (37.0-65.0)	1222
Age group							
20-59 years	01-02	**16.6** (13.0-21.1)	**16.1** (11.9-22.2)	**31.7** (23.9-40.4)	**55.5** (44.5-68.6)	**72.1** (57.3-105)	744
	03-04	**10.2** (8.56-12.2)	**10.0** (8.50-13.0)	**20.0** (17.0-24.0)	**35.0** (29.0-40.0)	**50.0** (37.0-65.0)	1222
Gender							
Males	01-02	**16.8** (12.0-23.5)	**16.1** (11.0-24.8)	**34.3** (22.4-48.7)	**57.0** (39.9-76.4)	**75.2** (54.5-156)	358
	03-04	**10.1** (8.43-12.1)	**10.0** (7.90-14.0)	**20.0** (17.0-25.0)	**36.8** (29.0-49.0)	**53.0** (36.8-69.0)	599
Females	01-02	**16.4** (13.4-20.1)	**16.6** (12.0-21.5)	**29.2** (24.0-36.5)	**53.5** (38.4-68.9)	**69.5** (53.3-104)	386
	03-04	**10.4** (8.41-12.7)	**10.0** (8.40-13.0)	**20.0** (16.0-23.9)	**33.0** (26.0-40.0)	**46.0** (35.0-65.0)	623
Race/ethnicity							
Mexican Americans	01-02	**17.0** (10.5-27.6)	**14.5** (10.0-32.7)	**35.1** (18.6-57.6)	**60.7** (41.5-100)	**93.0** (49.7-243)	223
	03-04	**9.17** (7.45-11.3)	**9.30** (7.60-11.0)	**19.0** (15.0-24.0)	**34.0** (24.0-44.4)	**44.4** (30.0-59.0)	225
Non-Hispanic blacks	01-02	**19.1** (12.9-28.1)	**20.9** (9.28-37.4)	**38.4** (27.7-46.0)	**55.9** (45.5-69.8)	**68.9** (51.9-74.0)	116
	03-04	**11.8** (9.54-14.6)	**12.0** (8.90-15.0)	**20.0** (15.0-30.0)	**35.0** (28.0-59.0)	**61.0** (34.0-100)	272
Non-Hispanic whites	01-02	**15.6** (12.0-20.2)	**15.2** (11.2-20.5)	**26.8** (20.4-39.5)	**53.5** (35.3-72.1)	**69.5** (53.5-105)	348
	03-04	**9.84** (8.09-12.0)	**10.0** (8.10-13.0)	**20.0** (16.0-23.0)	**33.8** (27.0-40.0)	**47.0** (35.0-67.0)	630

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 2.37 and 2.11.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.

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Benzophenone-3

CAS No. 131-57-7

General Information

Benzophenone-3 (2-hydroxy-4-methoxybenzophenone) occurs naturally in some flowering plants. It is commercially synthesized as a sunscreen for use in lotions, conditioners, and cosmetics. It is also used as a UV stabilizer in plastic surface coatings and polymers. Benzophenone-3 is a common ingredient in sun-blocking agents.

People may be exposed through dermal application of sunscreens and cosmetic products. Small amounts of benzophenone-3 can be absorbed through human skin and excreted in the urine, mostly as a glucuronidated conjugate (Gonzalez et al., 2006; Gustavsson et al., 2002; Janjua et al., 2004; Ye et al., 2005). After dermal application of a 4% lotion over the entire body daily for 5 days, one study found that 1.2-8.7% of the applied benzophenone-3 amount was recovered in the urine (Gonzalez et al., 2006).

Human health effects from benzophenone-3 at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Following dermal application, some cases of photoallergy or allergy to benzophenone-3 have been reported. Male reproductive toxicity has been inconsistently reported in chronic high dose animal studies (Daston et al., 1993; French, 1992). Benzophenone-3 has weak estrogenic activity or weak anti-androgenic activity (French, 1992; Schlecht et al., 2004; Schlumpf et al., 2001; Schreurs et al., 2005). No human hormonal changes were observed during four days of application of 10% benzophenone-3 lotion (Janjua et al., 2004). Benzophenone-3 is not considered mutagenic (Robison et al., 1994). IARC and NTP have no ratings as to human carcinogenicity of benzophenone-3.

Biomonitoring Information

Urinary benzophenone-3 levels include both conjugated and unconjugated forms and reflect recent exposure to the chemical. The NHANES 2003-2004 levels of urinary benzophenone-3 have been described by Calafat et al. (2008). The analysis showed that female participants had slightly higher urinary levels than males and that non-Hispanic whites were more likely than non-Hispanic blacks to have levels above the 95th percentile of the overall population. In a study of 90 U.S. females aged 6-8 years, the median urinary benzophenone-3 level of 14.7 µg/L was comparable to the median level of children 6-11 years of age (17.2 µg/L) in the NHANES 2003-2004 subsample (Calafat et al., 2008; Wolff et al., 2007). Total benzophenone-3 urinary concentrations were detectable in 90% of a small sample of adults in whom the values ranged up to 3000 µg/L (Ye et al., 2005). Following short-term application of 10% benzophenone-3 lotion, men and women had mean urinary levels of 140 and 60 µg/L, respectively (Janjua et al., 2004).

Finding a measurable amount of benzophenone-3 in urine does not mean that the levels of benzophenone-3 cause an adverse health effect. Biomonitoring studies on levels of benzophenone-3 provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of benzophenone-3 than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Benzophenone-3 (2-Hydroxy-4-methoxybenzophenone)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**22.9** (18.1-28.9)	**18.1** (15.5-23.2)	**94.0** (67.5-123)	**370** (225-570)	**1040** (698-1390)	2517
Age group							
6-11 years	03-04	**21.2** (16.4-27.3)	**17.2** (14.9-25.9)	**66.7** (38.7-102)	**158** (106-246)	**246** (154-618)	314
12-19 years	03-04	**22.9** (18.0-29.3)	**20.1** (16.1-25.1)	**67.1** (45.2-93.8)	**170** (137-240)	**407** (183-717)	715
20 years and older	03-04	**23.1** (18.0-29.6)	**18.1** (14.7-23.3)	**109** (72.1-140)	**450** (315-733)	**1220** (769-1750)	1488
Gender							
Males	03-04	**16.8** (13.2-21.3)	**13.7** (11.4-16.8)	**55.3** (33.2-86.6)	**178** (134-324)	**567** (238-1350)	1229
Females	03-04	**30.7** (23.7-39.8)	**26.0** (20.2-34.1)	**137** (106-172)	**596** (403-769)	**1340** (776-1790)	1288
Race/ethnicity							
Mexican Americans	03-04	**16.5** (10.9-25.1)	**11.9** (8.50-18.3)	**45.5** (25.9-78.2)	**178** (76.4-412)	**412** (178-2180)	613
Non-Hispanic blacks	03-04	**12.8** (9.38-17.4)	**10.2** (7.40-14.4)	**34.3** (22.8-50.6)	**127** (90.8-176)	**247** (143-499)	652
Non-Hispanic whites	03-04	**27.7** (20.3-37.8)	**24.4** (16.8-32.0)	**121** (83.6-162)	**507** (316-769)	**1340** (733-2070)	1092

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.

Urinary Benzophenone-3 (2-Hydroxy-4-methoxybenzophenone) (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**22.2** (17.6-28.0)	**16.2** (12.7-21.6)	**82.0** (58.7-108)	**415** (283-577)	**1080** (686-1600)	2514
Age group							
6-11 years	03-04	**25.8** (19.5-34.1)	**22.4** (14.4-33.7)	**84.6** (41.0-131)	**171** (132-365)	**427** (171-710)	314
12-19 years	03-04	**17.2** (13.7-21.5)	**12.9** (10.4-16.5)	**43.6** (29.5-57.7)	**136** (91.7-239)	**350** (173-646)	713
20 years and older	03-04	**22.8** (17.8-29.1)	**16.2** (12.7-21.9)	**93.2** (66.0-130)	**491** (361-700)	**1330** (880-1880)	1487
Gender							
Males	03-04	**13.6** (10.8-17.1)	**10.3** (8.36-12.9)	**40.0** (24.9-62.5)	**169** (93.3-316)	**381** (229-685)	1228
Females	03-04	**35.5** (27.1-46.4)	**28.2** (20.2-37.0)	**144** (101-224)	**686** (491-1130)	**1850** (1220-2580)	1286
Race/ethnicity							
Mexican Americans	03-04	**15.1** (9.44-24.0)	**11.1** (6.95-16.0)	**40.7** (18.3-85.8)	**158** (87.4-362)	**595** (118-1860)	612
Non-Hispanic blacks	03-04	**8.78** (6.49-11.9)	**6.80** (5.27-9.00)	**19.7** (13.5-33.4)	**79.8** (46.8-139)	**185** (79.8-536)	651
Non-Hispanic whites	03-04	**28.3** (20.6-38.8)	**22.0** (14.6-32.7)	**116** (73.5-175)	**510** (380-760)	**1330** (852-2410)	1091

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Bisphenol A

CAS No. 80-05-7

General Information

Bisphenol A is a phenolic chemical which has been used for over 50 years in the manufacture of polycarbonate plastics and epoxy resins; in thermal paper production; and as a polymerization inhibitor in the formation of some polyvinyl chloride plastics. Polycarbonates are used to make products such as compact discs, automobile parts, baby bottles, plastic dinnerware, eyeglass lenses, toys, and impact-resistant safety equipment. Epoxy resins containing bisphenol A are used in protective linings of some canned food containers, wine vat linings, epoxy resin-based paints, floorings, and some dental composites. In recent years, about 5-6 billion pounds of bisphenol were produced annually worldwide. Bisphenol A may enter the environment from industrial sources or from product leaching, disposal, and use. In 1999-2000, bisphenol A was detected in 41.2% of 139 U.S. streams in 30 states (Kolpin et al., 2002). Bisphenol A can be biodegraded and does not bioaccumulate significantly in aquatic organisms. Some invertebrates may be sensitive and show reproductive effects (European Commission, 2003).

General population exposure to bisphenol A may occur through ingestion of foods in contact with bisphenol A containing materials. For small children, hand-to-mouth and direct oral contact with materials containing bisphenol A are possible. Exposure from indoor air is a small component of total exposure estimates (Wilson et al., 2007. In animal and human studies, bisphenol A is well absorbed orally. In humans, little free bisphenol A circulates after oral absorption due to the high degree of glucuronidation by the liver. The glucuronidated bisphenol A is excreted in the urine within 24 hours with no evidence of accumulation (Volkel et al., 2002).

Human health effects from bisphenol A at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Occupational exposure of epoxy workers to bisphenol A dust may produce eye irritation and skin sensitization. In animal studies, bisphenol A has low acute toxicity. It is not considered a teratogen (Kim et al., 2001). Bisphenol A is rated as weakly estrogenic (Matthews et al., 2001). Some reproductive or developmental changes are observed at high doses in standard experimental animal studies (e.g., delayed vaginal opening and preputial separation) (Ema et al., 2001; Tyl et al., 2002; NTP-CERHR, 2008). Reproductive and neurodevelopmental effects of bisphenol A at low doses in animals, including environmental doses potentially relevant to humans, have been the subject of ongoing scientific reviews and study (European Commission, 2002; Gray et al., 2004; NTP, 2001; NTP-CERHR, 2007 and 2008; vom Saal and Hughes, 2005 Welshons et al., 2006; Witorsch, 2002). Examples of recent animal studies which suggest possible low dose effects include altered development of the fetal prostate and mammary gland, inhibition of postnatal testosterone production, and changes in neurodevelopment (Akingbemi et al., 2004; Leranth et al., 2008; NTP-CERHR, 2007;

Urinary Bisphenol A (2,2-*bis*[4-Hydroxyphenyl] propane)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**2.64** (2.38-2.94)	**2.80** (2.50-3.10)	**5.50** (5.00-6.20)	**10.6** (9.40-12.0)	**16.0** (14.4-17.2)	2517
Age group							
6-11 years	03-04	**3.55** (2.95-4.29)	**3.80** (2.70-5.00)	**6.90** (6.00-8.30)	**12.6** (9.50-15.1)	**16.0** (11.5-23.3)	314
12-19 years	03-04	**3.74** (3.31-4.22)	**4.30** (3.60-4.60)	**7.80** (6.50-9.00)	**13.5** (11.8-15.2)	**16.5** (15.2-20.9)	715
20 years and older	03-04	**2.41** (2.15-2.72)	**2.60** (2.30-2.80)	**5.10** (4.50-5.70)	**9.50** (8.10-11.3)	**15.2** (12.4-18.1)	1488
Gender							
Males	03-04	**2.92** (2.63-3.24)	**3.20** (2.70-3.60)	**6.10** (5.40-6.60)	**10.4** (9.50-11.6)	**16.0** (12.7-17.6)	1229
Females	03-04	**2.41** (2.11-2.75)	**2.50** (2.20-2.80)	**5.00** (4.20-6.20)	**10.6** (8.70-12.5)	**15.9** (13.5-20.1)	1288
Race/ethnicity							
Mexican Americans	03-04	**2.58** (2.15-3.08)	**2.60** (2.10-3.20)	**5.20** (4.40-6.50)	**9.90** (7.30-13.9)	**15.4** (10.2-19.7)	613
Non-Hispanic blacks	03-04	**4.24** (3.73-4.82)	**4.30** (3.80-5.10)	**8.20** (7.10-9.80)	**14.2** (11.7-16.9)	**20.6** (14.9-25.2)	652
Non-Hispanic whites	03-04	**2.51** (2.26-2.79)	**2.70** (2.50-3.00)	**5.20** (4.70-5.80)	**9.60** (8.30-10.9)	**15.1** (12.6-16.7)	1092

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.

Timms et al., 2005).

Bisphenol A is not considered mutagenic and is unlikely to be a carcinogen, although it may form DNA adducts *in vitro* and inhibit mitotic spindle activity (Haighton et al., 2002). IARC and NTP do not have ratings for bisphenol A with respect to human carcinogenicity. The epoxy resin oligomer, bisphenol A diglycidyl ether, has limited evidence of animal carcinogenicity and is not classifiable as a human carcinogen by IARC.

Biomonitoring Information

Urinary levels of bisphenol A include both conjugated and unconjugated forms and reflect recent exposure to the chemical. In the participants of NHANES 2003-2004, prevalent exposure to bisphenol A in the U.S. population was demonstrated with children, females, and lower income strata having slightly higher urinary levels (Calafat et al., 2008). This study confirmed levels seen in an earlier smaller sample of 394 U.S. residents (Calafat et al., 2005). Several previous small studies in Japanese pregnant women, Japanese university students, and Korean residents have found mean urinary bisphenol A levels to be similar or up to several times higher than those in the U.S. representative NHANES 2003-2004 subsample (Fujimaki et al., 2004; Kim et al., 2003; Ouchi and Watanabe, 2002), although one study of 73 Koreans found levels that averaged seven times higher than median levels in the NHANES 2003-2004 subsample (Yang et al., 2003; Calafat et al., 2008). Applications of certain dental sealants were shown to increase urinary levels of bisphenol A for 24 hours (Joskow et al., 2006). Hanaoka et al. (2002) studied workers with exposure to bisphenol A diglycidyl ether and found mean urinary levels of bisphenol A about double that of unexposed workers.

Finding a measurable amount of bisphenol A in the urine does not mean that the levels of bisphenol A cause an adverse health effect. Biomonitoring studies on levels of bisphenol A provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of bisphenol A than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Bisphenol A (2,2-*bis*[4-Hydroxyphenyl] propane) (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**2.58** (2.36-2.82)	**2.50** (2.31-2.80)	**4.29** (3.88-4.75)	**7.67** (6.62-8.66)	**11.2** (9.78-12.4)	
Age group							
6-11 years	03-04	**4.32** (3.63-5.14)	**4.29** (3.63-5.23)	**7.14** (5.83-9.56)	**12.2** (9.84-14.8)	**15.7** (12.2-23.2)	
12-19 years	03-04	**2.80** (2.52-3.11)	**2.74** (2.35-3.22)	**4.74** (4.21-5.09)	**7.79** (6.41-8.87)	**11.8** (8.05-14.2)	
20 years and older	03-04	**2.39** (2.17-2.64)	**2.36** (2.15-2.59)	**3.93** (3.44-4.33)	**6.64** (5.97-7.74)	**10.0** (9.01-11.4)	
Gender							
Males	03-04	**2.38** (2.15-2.63)	**2.31** (2.08-2.70)	**4.19** (3.81-4.64)	**7.10** (6.41-8.28)	**9.94** (9.06-11.7)	
Females	03-04	**2.78** (2.50-3.08)	**2.68** (2.40-2.94)	**4.41** (3.81-5.15)	**7.93** (6.48-10.2)	**12.4** (9.29-18.2)	
Race/ethnicity							
Mexican Americans	03-04	**2.34** (2.02-2.71)	**2.38** (2.00-2.65)	**3.85** (3.24-4.55)	**7.09** (5.00-9.04)	**10.9** (8.50-14.3)	
Non-Hispanic blacks	03-04	**2.92** (2.58-3.32)	**2.95** (2.51-3.27)	**4.90** (4.07-6.13)	**8.64** (7.53-9.63)	**11.9** (10.2-13.3)	
Non-Hispanic whites	03-04	**2.58** (2.37-2.81)	**2.55** (2.32-2.80)	**4.30** (3.93-4.67)	**7.58** (6.32-8.87)	**11.0** (9.34-12.4)	

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4-*tert*-Octylphenol

CAS No. 140-66-9

General Information

4-*tert*-Octyphenol, an alkylphenol, is used to manufacture alkylphenol ethoxylates, which are anionic surfactants used in detergents, industrial cleaners, and emulsifiers. Commercial formulations of alkylphenol ethoxylates usually contain a mixture of oligomers and isomers, and the polyethoxy chain may consist of up to 50 ethoxy units. Less frequently, the various alkylphenols have also been used as emulsifiers and modifiers in paints, pesticides, textiles, and some personal care products. Alkylphenols also have been used as plasticizers and antioxidants in plastics and resins. In the 1990s, over 500,000 tons of alkylphenol ethoxylates were produced annually worldwide. Nonylphenol ethoxylates are more commonly used than octylphenol ethoxylates. The alkylphenol ethoxylates enter the environment through human use of products containing them, through sewage, and through manufacturing waste streams (Warhurst, 1995; Ying et al., 2002). They are biodegraded to the corresponding alkylphenol (octylphenol or nonylphenol); to shorter chain alkylphenol ethoxylates; and to alkylphenoxycarboxylates. Octylphenols and nonylphenols can also enter the environment directly from manufacturing waste streams. During the 1980s and 1990s, several European nations banned the use of alkylphenol ethoxylates in domestic detergents and other uses. The alkylphenols can bioaccumulate in some fish, and some of their degradation products are toxic to aquatic life. In 1999-2000, 4-octylphenol monoethoxylate was detected in 43.5% of 139 U.S. streams in 30 states (Kolpin et al., 2002).

Human exposure to alkylphenols and alkylphenol ethoxylates may occur through ingestion of contaminated foods (e.g., fish) and drinking water, and from contact with some personal care products and detergents. Indoor and to a lesser extent, outdoor air may have detectable levels of 4-*tert*-octylphenol and 4-*tert*-octylphenol monoethoxylates, leading to inhalation as another potential exposure route (Rudel et al., 2003; Saito et al., 2004). In rats, orally administered 4-*tert*-octylphenol was well absorbed, did not bioaccumulate, and was quickly eliminated from the blood (Certa et al., 1996). Disposition in humans has not been studied sufficiently.

Human health effects from 4-*tert*-octylphenol or the corresponding octylphenol ethoxylates at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Several alkylphenols, including 4-*tert*-octylphenol, have demonstrated estrogenic effects particularly when injected at high doses in animals. These high dose parenteral effects of 4-*tert*-octylphenol have included altered sex hormone levels and hypothalamic-pituitary suppression, impaired steroidogenesis, altered estrus cycles and reproductive outcomes, altered neonatal sexual development, testicular atrophy, and impaired spermatogenesis (e.g., Bian et al., 2006; Blake and Boockfor, 1997; Katsuda et al., 2000; Laws et al., 2000;

Urinary 4-*tert*-Octylphenol (4-[1,1,3,3-Tetramethylbutyl] phenol)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**.300** (<LOD-.500)	**.900** (.600-1.30)	**1.70** (1.20-2.40)	**2.30** (1.60-3.20)	2517
Age group							
6-11 years	03-04	**.357** (.268-.477)	**.400** (.200-.500)	**.900** (.600-1.40)	**1.70** (1.20-2.10)	**2.10** (1.50-2.90)	314
12-19 years	03-04	**.369** (.274-.497)	**.400** (.200-.600)	**1.10** (.600-1.60)	**1.80** (1.20-2.50)	**2.40** (1.60-3.20)	715
20 years and older	03-04	*	**.300** (<LOD-.500)	**.900** (.500-1.30)	**1.70** (1.10-2.40)	**2.30** (1.60-3.20)	1488
Gender							
Males	03-04	*	**.300** (<LOD-.500)	**1.00** (.500-1.50)	**1.80** (1.20-2.40)	**2.20** (1.60-3.90)	1229
Females	03-04	*	**.300** (<LOD-.400)	**.900** (.600-1.20)	**1.70** (1.20-2.30)	**2.30** (1.50-3.00)	1288
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**.500** (.300-.600)	**.900** (.600-1.40)	**1.30** (.800-1.80)	613
Non-Hispanic blacks	03-04	**.389** (.299-.507)	**.400** (.300-.600)	**1.10** (.700-1.50)	**2.00** (1.30-2.60)	**2.50** (1.60-3.10)	652
Non-Hispanic whites	03-04	*	**.300** (<LOD-.600)	**1.00** (.600-1.50)	**1.80** (1.20-2.50)	**2.30** (1.60-3.60)	1092

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Myllymaki et al., 2005; Nagao et al., 2001; Sweeney et al., 2000; Yoshida et al., 2001). It is unclear if estrogenic or other effects occur in animals through oral dosing, at lower or environmentally relevant doses (Blake et al., 2004; Tyl et al., 1999). 4-*tert*-Octylphenol is not considered directly genotoxic. IARC and NTP have not rated octylphenol, nonylphenol, or their corresponding ethoxylates with respect to human carcinogenicity.

Biomonitoring Information

Urinary levels of 4-*tert*-octyphenol reflect recent exposure. Calafat et al. (2008) showed that urinary levels of 4-*tert*-octyphenol were detectable in slightly greater than half of the participants of the U.S. representative subsample of NHANES 2003-2004. In a small number of adult Japanese volunteers, the urinary concentrations of 4-*tert*-octyphenol were near or below the detection limit (Inoue et al. 2003; Kawaguchi et al. 2004).

Finding measurable amounts of 4-*tert*-octylphenol in the urine does not mean that the levels of 4-*tert*-octylphenol cause an adverse health effect. Biomonitoring studies on levels of 4-*tert*-octylphenol provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of 4-*tert*-octylphenol than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 4-*tert*-Octylphenol (4-[1,1,3,3-Tetramethylbutyl] phenol) (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**.320** (<LOD-.470)	**.860** (.550-1.25)	**1.85** (1.31-2.54)	**2.76** (2.02-4.00)	2514
Age group							
6-11 years	03-04	**.435** (.337-.560)	**.460** (.280-.610)	**1.17** (.730-1.62)	**2.03** (1.67-2.15)	**2.50** (2.03-6.00)	314
12-19 years	03-04	**.276** (.199-.384)	**.270** (.160-.450)	**.740** (.470-1.22)	**1.62** (1.11-2.59)	**2.62** (1.53-3.68)	713
20 years and older	03-04	*	**.300** (<LOD-.450)	**.850** (.540-1.25)	**1.81** (1.25-2.71)	**2.78** (1.96-4.14)	1487
Gender							
Males	03-04	*	**.260** (<LOD-.420)	**.740** (.470-1.11)	**1.59** (1.05-2.29)	**2.40** (1.65-3.33)	1228
Females	03-04	*	**.370** (<LOD-.530)	**1.00** (.630-1.43)	**2.20** (1.43-3.00)	**3.33** (2.40-4.78)	1286
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**.410** (.270-.620)	**.910** (.640-1.43)	**1.64** (.890-2.73)	612
Non-Hispanic blacks	03-04	**.269** (.207-.349)	**.270** (.170-.400)	**.770** (.500-1.08)	**1.60** (1.10-2.11)	**2.31** (1.68-2.78)	651
Non-Hispanic whites	03-04	*	**.380** (<LOD-.570)	**1.00** (.620-1.41)	**2.03** (1.36-3.00)	**3.06** (2.18-4.24)	1091

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Triclosan

CAS No. 3380-34-5

General Information

Triclosan is a phenolic diphenyl ether used for over 30 years as a preservative and antiseptic agent. It acts by inhibiting bacterial fatty acid synthesis. Triclosan has been added to soaps, toothpastes, mouthwashes, acne medications, deodorants, and wound disinfection solutions, and has also been impregnated into some kitchen utensils, toys, and medical devices. Triclosan enters the aquatic environment mainly through residential wastewaters. It can be photochemically and biologically degraded, a process that can result in the formation of small amounts of 2,8-dichlorodibenzo-p-dioxin (Aranami et al., 2007; Mezcua et al., 2004). In 1999-2000, triclosan was found in 57.6% of 139 U.S. streams sampled in 30 states (Kolpin et al., 2002). Triclosan has a low bioaccumulation potential in fish. There is some concern that widespread use of triclosan and other biocides can alter antibiotic resistance in bacteria (Aiello et al., 2007).

General population exposure results from dermal and oral use of products containing triclosan. Triclosan can remain present in the oral saliva for several hours after the use of toothpaste containing triclosan (Gilbert et al., 1987). Triclosan can be absorbed across skin into the blood stream. In the body it is conjugated to glucuronides and sulfates (Bodey et al., 1976; Moss et al., 2000). In animal and human studies, it is excreted over several days in the feces and urine as primarily as unchanged triclosan (Kanetoshi et al., 1988; (Sandborgh-Englund et al., 2006).

Human health effects from triclosan at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Triclosan formulations may rarely cause skin irritation. In animal studies, it has low acute toxicity. Some reports show endocrine effects are observed in amphibians and fish (Foran et al., 2000; Matsumura et al., 2005; Veldhoen et al., 2007). Triclosan is not considered teratogenic at maternally toxic doses, and has not been considered mutagenic or carcinogenic (Bhargava and Leonard, 1996; Lyman and Furia, 1969). IARC and NTP do not have ratings with respect to human carcinogenicity.

Biomonitoring Information

Urinary triclosan levels reflect recent exposure. In a U.S. representative subsample of NHANES 2003-2004, Calafat et al., 2008 has shown higher levels during the third decade of life and among people with the highest household income, but not by race/ethnicity and sex. In a study of 90 U.S. young girls, the median urinary triclosan level of 7.2 µg/L was comparable to the median level (8.2 µg/L) of children 6-11 years of age who participated in NHANES 2003-2004 (Wolff et al., 2007; Calafat et al., 2008).

Finding measurable amounts of triclosan in the urine does not mean that the levels of triclosan cause an adverse health effect. Biomonitoring studies on levels of triclosan provide physicians and public health officials with a reference values so that they can determine whether people have been exposed to higher levels of triclosan than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Triclosan (2,4,4'-Trichloro-2'-hydroxyphenyl ether)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**13.0** (11.6-14.6)	**9.20** (7.90-10.9)	**47.4** (38.2-58.4)	**249** (188-304)	**461** (383-522)	2517
Age group							
6-11 years	03-04	**8.16** (6.20-10.8)	**6.00** (4.00-8.50)	**20.7** (14.3-31.6)	**123** (36.4-163)	**157** (113-380)	314
12-19 years	03-04	**14.5** (11.0-19.1)	**10.3** (8.20-13.1)	**39.0** (26.5-86.4)	**304** (134-566)	**655** (310-890)	715
20 years and older	03-04	**13.6** (12.0-15.3)	**9.60** (8.20-11.5)	**51.7** (39.6-65.7)	**261** (198-317)	**472** (406-522)	1488
Gender							
Males	03-04	**16.2** (13.4-19.6)	**11.7** (9.30-14.8)	**84.9** (50.6-111)	**317** (231-433)	**574** (461-716)	1229
Females	03-04	**10.6** (9.29-12.1)	**7.60** (6.10-9.10)	**33.2** (27.1-39.4)	**144** (96.5-250)	**380** (258-430)	1288
Race/ethnicity							
Mexican Americans	03-04	**14.6** (10.6-20.1)	**8.80** (5.40-17.5)	**65.4** (32.8-127)	**357** (225-456)	**597** (372-992)	613
Non-Hispanic blacks	03-04	**14.4** (11.4-18.2)	**11.1** (8.70-16.1)	**37.6** (30.2-58.0)	**203** (87.5-341)	**450** (254-750)	652
Non-Hispanic whites	03-04	**12.9** (11.2-14.9)	**9.20** (7.40-11.0)	**49.2** (37.8-63.4)	**245** (163-334)	**461** (383-527)	1092

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 2.3.

Urinary Triclosan (2,4,4'-Trichloro-2'-hydroxyphenyl ether) (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**12.7** (11.5-14.1)	**9.48** (8.22-10.4)	**43.9** (33.8-60.6)	**212** (172-241)	**368** (294-463)	2514
Age group							
6-11 years	03-04	**9.93** (7.43-13.3)	**7.55** (4.72-13.4)	**25.1** (15.3-35.6)	**116** (39.9-236)	**236** (115-336)	314
12-19 years	03-04	**10.9** (8.32-14.2)	**7.45** (5.48-10.7)	**31.8** (21.9-61.1)	**193** (90.7-318)	**356** (169-580)	713
20 years and older	03-04	**13.4** (12.0-15.1)	**10.0** (8.89-11.4)	**50.0** (36.0-73.8)	**224** (186-272)	**385** (308-506)	1487
Gender							
Males	03-04	**13.2** (11.3-15.6)	**9.21** (6.86-12.1)	**73.1** (45.8-85.9)	**237** (175-294)	**384** (294-506)	1228
Females	03-04	**12.2** (10.6-14.2)	**9.54** (8.45-10.4)	**32.3** (26.2-46.6)	**182** (138-217)	**336** (225-480)	1286
Race/ethnicity							
Mexican Americans	03-04	**13.3** (9.38-18.8)	**9.18** (5.45-13.9)	**66.7** (28.8-112)	**292** (151-432)	**453** (263-1150)	612
Non-Hispanic blacks	03-04	**9.94** (7.92-12.5)	**7.74** (5.50-10.0)	**30.2** (25.6-37.3)	**132** (78.0-213)	**260** (127-513)	651
Non-Hispanic whites	03-04	**13.3** (11.6-15.1)	**9.82** (8.11-11.5)	**47.0** (34.3-67.7)	**213** (160-272)	**358** (276-480)	1091

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Pentachlorophenol

CAS No. 87-86-5

Also a Metabolite of Several Organochlorine Insecticides

General Information

Pentachlorophenol (PCP) and its sodium salt were once widely used as a fungicide, bactericide, herbicide, mollusicide, algaecide and insecticide. Since 1984, PCP use in the U.S. has been restricted, and it is used primarily as a preservative for wood to be used outdoors (e.g., utility poles and fence posts). PCP cannot be used on wood in residential or agricultural buildings. PCP has been detected in soils, air, water and sediments because of the large amounts that were produced and used historically. In the environment, PCP is degraded by sunlight and metabolized rapidly by microorganisms, plants, and animals, so it is relatively non-persistent. General population exposure to PCP may occur by inhalation of contaminated air, ingestion of contaminated food or water, and dermal contact with PCP-treated products. Human exposure to PCP has become less common. Workers who manufacture or apply PCP may inhale it or absorb it through exposed skin.

PCP is absorbed rapidly and well by all exposure routes. After absorption, PCP is distributed to most tissues and is not extensively metabolized. The parent compound and conjugates, along with small amounts of tetrachlorohydroquinone and conjugates, are eliminated in the urine. After a single dose, PCP is eliminated over a few days (Braun et al., 1979); with repeated or chronic exposure, the elimination half-life may be a week or more (Uhl et al., 1986). PCP also may be eliminated in urine as a metabolite of hexachlorobenzene, other polychlorinated benzenes, and possibly of lindane (IPCS, 2002; Kohli et al., 1976; To-Figueras et al., 1997).

Human health effects from PCP at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Acute, high dose exposure to PCP can induce a hypermetabolic state and excessive heat production as a result of uncoupling mitochondrial oxidative phosphorylation. Effects including hyperthermia, hypertension, and metabolic acidosis were observed in

Urinary Pentachlorophenol

Also a Metabolite of Several Organochlorine Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.390** (.350-.960)	**1.30** (.500-2.10)	1994
	01-02	*	**< LOD**	**< LOD**	**1.23** (.590-1.76)	**1.94** (1.58-2.53)	2528
Age group							
6-11 years	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.770** (.350-1.51)	**1.65** (.990-2.00)	482
	01-02	*	**< LOD**	**< LOD**	**1.37** (.890-1.70)	**2.10** (1.58-2.75)	577
12-19 years	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.660** (.350-2.60)	**2.00** (.510-5.90)	681
	01-02	*	**< LOD**	**< LOD**	**1.48** (.850-2.30)	**2.30** (1.47-5.04)	826
20-59 years	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.350** (.350-.650)	**1.10** (.350-2.00)	831
	01-02	*	**< LOD**	**< LOD**	**1.01** (<LOD-1.76)	**1.90** (1.45-2.53)	1125
Gender							
Males	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.630** (.350-1.30)	**1.40** (.480-2.60)	973
	01-02	*	**< LOD**	**< LOD**	**1.32** (.680-1.80)	**1.94** (1.47-3.09)	1190
Females	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.350** (.350-.530)	**.890** (.350-2.00)	1021
	01-02	*	**< LOD**	**< LOD**	**1.10** (<LOD-1.78)	**1.98** (1.54-2.42)	1338
Race/ethnicity							
Mexican Americans	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.350** (.350-.350)	**.650** (.350-1.90)	696
	01-02	*	**< LOD**	**< LOD**	**.990** (<LOD-2.37)	**1.62** (.510-3.64)	680
Non-Hispanic blacks	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.980** (.350-2.50)	**1.65** (.860-2.70)	521
	01-02	*	**< LOD**	**< LOD**	**1.73** (1.33-2.33)	**2.83** (2.08-3.67)	696
Non-Hispanic whites	99-00	*	**.350** (.350-.350)	**.350** (.350-.350)	**.390** (.350-1.10)	**1.30** (.350-2.30)	603
	01-02	*	**< LOD**	**< LOD**	**1.18** (<LOD-1.76)	**1.91** (1.48-2.42)	951

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.25 and 0.5.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

adults and children severely exposed to PCP through ingestion, inhalation, or skin absorption. Death can result from seizures and cardiovascular collapse. In animals, chronically administered high doses of PCP were hepatotoxic, carcinogenic, and adversely affected thyroid function (U.S.EPA, 2004; van Raaij et al., 1991). Pentachlorophenol is not mutagenic or teratogenic. IARC has determined that pentachlorophenol is possibly carcinogenic to humans.

The U.S. EPA has developed standards for PCP in drinking water and the environment, and the FDA has established a standard for bottled water. OSHA has established an occupational standard. More information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA at: http://www.epa.gov/pesticides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

In NHANES 1999-2000 the median urinary PCP levels among children aged 6-11 and 12-19 years were as much as thirteen times lower compared to a sample of German children aged 6-14 years in 1990-1992 (4.6 and 14.9 µg/L, respectively) (Seifert et al., 2000). Among adults in the NHANES 1999-2000 subsample, the median and 95th percentile urinary PCP levels were approximately three times lower than comparable values in German adults (2.08 and 5.0 µg/L, respectively) (Becker et al., 2003). In NHANES 2001-2002 subsamples, urinary PCP levels at the 95th percentile were approximately fivefold lower than 95th percentile values measured in a nonrandom subsample from NHANES III (1988-1994) participants (Hill et al., 1995). Urinary PCP levels at the 95th percentile in this *Report* are approximately half the corresponding 95th percentile values found in German adults evaluated in 1998 (Becker et al., 2003). In a small sample of U.S. children in the 1980's, the 95th percentile of urinary PCP levels was about fiftyfold higher than that for 6-11 year olds in NHANES 2001-2002 (Hill et al., 1989). Urinary levels of pentachlorophenol in the general population are far below (hundreds of times lower than) urine levels reported for workplace exposure to PCP or among people living in PCP-treated log homes (Cline et al., 1989).

Urinary Pentachlorophenol (creatinine corrected)

Also a Metabolite of Several Organochlorine Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.300** (.290-.320)	**.570** (.500-.650)	**1.16** (.950-1.35)	**1.67** (1.35-2.11)	1994
	01-02	*	**< LOD**	**< LOD**	**1.52** (1.25-1.75)	**2.26** (1.67-3.09)	2527
Age group							
6-11 years	99-00	*	**.370** (.340-.420)	**.650** (.580-.780)	**.990** (.900-1.30)	**1.83** (1.10-2.95)	482
	01-02	*	**< LOD**	**< LOD**	**1.84** (1.29-3.18)	**3.18** (1.84-4.52)	577
12-19 years	99-00	*	**.250** (.220-.290)	**.400** (.330-.490)	**.760** (.500-1.40)	**1.57** (.700-2.51)	681
	01-02	*	**< LOD**	**< LOD**	**1.21** (.910-1.56)	**1.82** (1.25-2.82)	825
20-59 years	99-00	*	**.300** (.270-.320)	**.610** (.510-.730)	**1.25** (1.00-1.40)	**1.67** (1.30-2.19)	831
	01-02	*	**< LOD**	**< LOD**	**1.52** (<LOD-1.75)	**2.19** (1.67-2.99)	1125
Gender							
Males	99-00	*	**.260** (.240-.280)	**.470** (.380-.560)	**.920** (.780-1.25)	**1.67** (1.16-1.84)	973
	01-02	*	**< LOD**	**< LOD**	**1.13** (.950-1.40)	**1.73** (1.25-2.92)	1190
Females	99-00	*	**.360** (.310-.430)	**.650** (.560-.830)	**1.26** (1.09-1.35)	**1.67** (1.35-2.19)	1021
	01-02	*	**< LOD**	**< LOD**	**1.75** (<LOD-2.06)	**2.69** (1.94-3.55)	1337
Race/ethnicity							
Mexican Americans	99-00	*	**.300** (.270-.320)	**.500** (.430-.560)	**1.06** (.710-1.40)	**1.57** (1.21-2.00)	696
	01-02	*	**< LOD**	**< LOD**	**1.09** (<LOD-2.36)	**1.94** (1.06-3.55)	680
Non-Hispanic blacks	99-00	*	**.250** (.220-.310)	**.440** (.360-.590)	**.850** (.590-1.30)	**1.34** (.950-1.90)	521
	01-02	*	**< LOD**	**< LOD**	**1.30** (.800-1.78)	**1.94** (1.48-2.79)	695
Non-Hispanic whites	99-00	*	**.320** (.290-.350)	**.630** (.510-.800)	**1.25** (1.00-1.40)	**1.67** (1.40-2.19)	603
	01-02	*	**< LOD**	**< LOD**	**1.52** (<LOD-1.78)	**2.10** (1.67-3.08)	951

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Finding a measurable amount of PCP in urine does not mean that the level of PCP causes an adverse health effect. Biomonitoring studies on levels of PCP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of PCP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research about PCP exposure and health effects.

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ortho-Phenylphenol

CAS No. 90-43-7

General Information

Ortho-phenylphenol (OPP, or 2-phenylphenol) and its water-soluble salt, sodium *ortho*-phenylphenate (SOPP), are antimicrobial agents used as bacteriostats, fungicides, and sanitizers. Both have been used in agriculture to control fungal and bacterial growth on stored crops, such as fruits and vegetables. SOPP is applied topically to the crop and then rinsed off, leaving the chemical residue OPP. Most agricultural food applications have been revoked, but OPP and SOPP are still used on pears and citrus (U.S.EPA, 2006). OPP is still used as a disinfectant fungicide for industrial applications, on ornamental plants and turfs, in paints, and as a wood preservative. In the past, it was used in home sanitizers for surfaces. OPP is volatile, and it has limited water solubility, whereas SOPP is not volatile and is more water soluble. Both chemicals degrade within hours to weeks in the environment (U.S. EPA, 2006).

General population exposure can occur via dermal, inhalational, or oral routes from residential use and by ingesting treated food or food that was in contact with treated surfaces or equipment. OPP was detected in 40 of 60 different canned beers at concentrations in the low parts per billion (Coelhan et al., 2006). Estimated human intakes have been below recommended intake limits (U.S.EPA, 2006). Workers who manufacture, formulate, or apply these chemicals may be more highly exposed than the general population. OPP is efficiently absorbed from the gastrointestinal tract and through the skin, and it is eliminated rapidly from the body as OPP glucuronide and sulfate conjugates (Bartels et al., 1998; Cnubben et al. 2002; Timchalk et al., 1998). Available evidence suggests that OPP does not accumulate in the body; however, small amounts of OPP have been measured in human adipose tissue (Onstot and Stanley, 1989).

Human health effects from OPP at low environmental doses or at biomonitored levels from low environmental exposures are unknown. OPP is considered to be moderately toxic after acute oral doses in animal studies. Chronic dosing in animals resulted in such systemic effects as weight loss and

Urinary *ortho*-Phenylphenol

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.497** (.390-.632)	**.490** (<LOD-.600)	**.850** (.600-1.30)	**1.50** (1.10-2.10)	**2.00** (1.60-3.80)	1991
	01-02	*	**< LOD**	**< LOD**	**.570** (.370-.860)	**1.27** (.710-2.85)	2529
Age group							
6-11 years	99-00	**.509** (.402-.645)	**.490** (<LOD-.630)	**.890** (.610-1.50)	**1.90** (1.30-2.10)	**2.20** (1.80-3.90)	480
	01-02	*	**< LOD**	**< LOD**	**1.17** (.760-2.02)	**2.30** (1.28-3.61)	577
12-19 years	99-00	**.508** (.370-.696)	**.490** (<LOD-.690)	**.890** (.570-1.50)	**1.60** (1.20-3.50)	**2.10** (1.40-7.20)	681
	01-02	*	**< LOD**	**< LOD**	**.740** (.480-1.34)	**2.33** (.800-3.09)	827
20-59 years	99-00	**.493** (.389-.624)	**.490** (<LOD-.600)	**.820** (.600-1.20)	**1.50** (1.10-1.90)	**2.00** (1.50-2.90)	830
	01-02	*	**< LOD**	**< LOD**	**.450** (<LOD-.670)	**.930** (.540-2.23)	1125
Gender							
Males	99-00	**.498** (.389-.638)	**.470** (<LOD-.640)	**.830** (.600-1.30)	**1.60** (1.20-2.00)	**2.00** (1.50-3.90)	973
	01-02	*	**< LOD**	**< LOD**	**.610** (.350-1.03)	**1.28** (.750-2.85)	1190
Females	99-00	**.496** (.386-.636)	**.490** (<LOD-.600)	**.860** (.580-1.30)	**1.50** (1.00-2.10)	**2.10** (1.50-4.50)	1018
	01-02	*	**< LOD**	**< LOD**	**.520** (.370-.790)	**1.22** (.590-2.91)	1339
Race/ethnicity							
Mexican Americans	99-00	**.552** (.364-.836)	**.420** (<LOD-.950)	**1.20** (.500-2.00)	**2.20** (1.40-5.80)	**3.80** (2.30-7.10)	695
	01-02	*	**< LOD**	**< LOD**	**1.14** (<LOD-3.88)	**2.92** (.560-8.22)	680
Non-Hispanic blacks	99-00	**.567** (.433-.742)	**.570** (.410-.780)	**.970** (.690-1.50)	**1.60** (1.40-2.00)	**2.00** (1.60-2.30)	520
	01-02	*	**< LOD**	**< LOD**	**.770** (.570-.890)	**1.19** (.840-1.76)	695
Non-Hispanic whites	99-00	**.466** (.349-.621)	**.450** (<LOD-.600)	**.770** (.550-1.20)	**1.40** (.880-2.10)	**1.90** (1.40-5.10)	603
	01-02	*	**< LOD**	**< LOD**	**.450** (<LOD-.710)	**1.07** (.570-2.23)	953

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.3 and 0.3.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

anemia, but no neurologic, reproductive, or developmental toxicity was observed (Bomhard et al., 2002; U.S.EPA 2006). OPP was not found to be mutagenic. Dermally applied OPP was not carcinogenic in a 2-year experimental study in animals (NTP, 1986). In high dose animal studies, OPP or SOPP produced carcinomas of the bladder only after phase II detoxification pathways were saturated, leading to production of two metabolites, *ortho*-phenylhydroquinone and *ortho*-phenylbenzoquinone. These metabolites may induce carcinogenicity via nongenotoxic regenerative hyperplasia of the bladder (Appel, 2000; Bomhard et al., 2002; Brusick, 2005; Kwok et al., 1999; Nakagawa et al., 1992; Smith et al., 1998; U.S.EPA 2006), or, less likely, by possible genotoxic mechanisms (Hagiwara et al., 1984; Ito et al., 1984; Murata et al., 1999; Pathak and Roy, 1993; Zhao et al., 2002). IARC has classified SOPP as a possible human carcinogen, and it has classified OPP as not classifiable with respect to human carcinogenicity. Additional information is available from U.S.EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary OPP levels reflect recent exposure. Detectable levels were seen in over half the U.S. population in the subsamples from NHANES 1999-2000 and 2001-2002 (CDC, 2005). Volunteers exposed to 0.4 mg dermally had urinary levels of OPP that were several hundred times higher than median levels found in NHANES 1999-2000 and 2001-2002 (Bartels et al., 1997; CDC, 2005).

Finding a measurable amount of OPP in urine does not mean that the level of OPP causes an adverse health effect. Biomonitoring studies on levels of OPP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of OPP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary *ortho*-Phenylphenol (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.444** (.353-.558)	**.410** (<LOD-.560)	**.840** (.620-1.11)	**1.84** (1.24-2.33)	**2.97** (2.04-4.29)	1991
	01-02	*	**< LOD**	**< LOD**	**.980** (.810-1.17)	**1.75** (1.21-2.33)	2528
Age group							
6-11 years	99-00	**.550** (.455-.666)	**.510** (<LOD-.670)	**1.02** (.800-1.27)	**1.96** (1.43-2.59)	**2.64** (2.09-3.58)	480
	01-02	*	**< LOD**	**< LOD**	**1.91** (1.08-2.53)	**2.69** (1.96-4.01)	577
12-19 years	99-00	**.343** (.248-.473)	**.320** (<LOD-.500)	**.690** (.460-.950)	**1.17** (.880-1.93)	**1.96** (1.09-6.32)	681
	01-02	*	**< LOD**	**< LOD**	**.780** (.640-1.21)	**1.52** (.940-2.32)	826
20-59 years	99-00	**.453** (.361-.568)	**.420** (<LOD-.570)	**.860** (.620-1.12)	**1.89** (1.24-2.47)	**3.28** (2.06-4.93)	830
	01-02	*	**< LOD**	**< LOD**	**.910** (<LOD-1.07)	**1.44** (1.05-2.30)	1125
Gender							
Males	99-00	**.382** (.301-.484)	**.360** (<LOD-.470)	**.750** (.550-.990)	**1.43** (1.08-1.93)	**2.09** (1.51-3.29)	973
	01-02	*	**< LOD**	**< LOD**	**.750** (.580-1.17)	**1.61** (.750-2.43)	1190
Females	99-00	**.514** (.403-.656)	**.470** (<LOD-.580)	**.910** (.650-1.46)	**2.06** (1.38-3.38)	**3.78** (2.06-5.96)	1018
	01-02	*	**< LOD**	**< LOD**	**1.11** (.910-1.38)	**1.75** (1.33-2.38)	1338
Race/ethnicity							
Mexican Americans	99-00	**.496** (.311-.791)	**.420** (<LOD-.810)	**1.11** (.560-2.31)	**3.00** (1.25-6.08)	**4.61** (2.40-13.4)	695
	01-02	*	**< LOD**	**< LOD**	**1.28** (<LOD-4.26)	**3.00** (.780-14.0)	680
Non-Hispanic blacks	99-00	**.385** (.291-.508)	**.380** (.270-.550)	**.670** (.510-.900)	**1.21** (.900-1.62)	**1.74** (1.43-2.13)	520
	01-02	*	**< LOD**	**< LOD**	**.670** (.480-.970)	**1.17** (.770-2.18)	694
Non-Hispanic whites	99-00	**.440** (.329-.590)	**.410** (<LOD-.610)	**.860** (.600-1.20)	**1.86** (1.12-2.59)	**2.93** (1.88-4.81)	603
	01-02	*	**< LOD**	**< LOD**	**.980** (<LOD-1.11)	**1.61** (1.11-1.91)	953

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Herbicides

Herbicides are used to control undesirable weeds and plants in agricultural, residential, and aquatic environments. More herbicides are used annually than insecticides, with about 553 million pounds of herbicides used in the U.S. during 2001 (U.S.EPA, 2004). The herbicides discussed in this *Report* can be classified into the following categories: chlorophenoxy acids, chloroacetanilides, and atrazine.

General population exposure may result from herbicides used in residential, forestal, or agricultural applications, from residues on food, or from contamination of drinking water. Workers who manufacture, formulate, or apply these chemicals have greater exposure to herbicides than others. The FDA, U.S.EPA, and OSHA have developed criteria for the allowable levels for many of these chemicals in foods, drinking water and other environmental media, and the workplace, respectively.

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3/17/09

Acetochlor

CAS No. 34256-82-1

General Information

Acetochlor is a chloroacetanilide type herbicide with restricted usage for preemergent control of grasses and broadleaf weeds on agricultural crop land, mainly corn. It is absorbed by plants and inhibits plant protein synthesis. Acetochlor is microbiologically degraded, remains in soils for up to 3 months, and has been detected in watersheds of agricultural lands (Battaglin et al., 2000; Hladik et al., 2005; Kolpin et al., 2000). Acetochlor degrades in water to acetochlor sulfonic acid and acetochlor oxanilic acid. Plants can degrade acetochlor to 2-ethyl-6-methylaniline, 2-hydroxyethyl-6-methylaniline, and hydroxymethyl ethyl aniline (U.S.EPA, 2006). Acetochlor is moderately toxic to fish and honey bees.

General population exposure to acetochlor may occur through diet or drinking water. Estimated human intakes of acetochlor have been below recommended limits (U.S.EPA, 2006). In animals, a major pathway for acetochlor metabolism involves mercapturate conjugation, but other pathways occur, including one that produces 2-methyl-6-ethylaniline and its reactive metabolite, the latter which may account for some observed effects (Coleman et al., 2000; Davison et al., 1994; Feng and Wratten, 1989; Jefferies et al., 1998). People exposed to acetochlor will excrete acetochlor mercapturate in their urine; however, this metabolite is not a marker of exposure to most plant metabolites or environmental degradates, which are often more prevalent in the environment.

Human health effects from acetochlor at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Acetochlor has low acute toxicity. Acetochlor has not shown developmental or fetal toxicity in chronic animal studies, but it has produced testicular atrophy, renal injury, and neurologic movement abnormalities (U.S.EPA 2000, 2006). Acetochlor is not mutagenic, and it is unlikely to be genotoxic at relevant doses (Ashby et al., 1996). However, in some species and at doses above maximum tolerated doses, animals have demonstrated tumors of the lung, nasal epithelia, and thyroid (U.S.EPA, 2000, 2006). U.S.EPA considers acetochlor likely to be carcinogenic in humans; NTP and IARC do not have ratings regarding human carcinogenicity. Additional information about external exposure (i.e., environmental levels) is available from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of acetochlor mercapturate reflect recent exposure. Urinary levels of acetochlor mercapturate were generally not detectable in the NHANES 2001-2002 subsample (CDC, 2005). Acetochlor mercapturate was measured in the urine of farmers actively spraying the pesticide and the geometric mean was 8.0 µg/L (Curwin et al., 2005). Urinary acetochlor mercapturate levels of 0.5 to 449 µg/L were measured in commercial applicators within 24 hours following its application (Barr et al., 2007).

Finding measurable amounts of acetochlor mercapturate in the urine does not mean that the levels of acetochlor mercapturate cause an adverse health effect. Biomonitoring studies on levels of acetochlor mercapturate provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of acetochlor than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Acetochlor mercapturate

Metabolite of Acetochlor

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2501
Age group							
6-11 years	01-02	*	< LOD	< LOD	< LOD	< LOD	576
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	820
20-59 years	01-02	*	< LOD	< LOD	< LOD	< LOD	1105
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1178
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1323
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	678
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	673
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	952

Limit of detection (LOD, see Data Analysis section) for Survey year 01-02 is 0.1.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Acetochlor mercapturate (creatinine corrected)

Metabolite of Acetochlor

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2500
Age group							
6-11 years	01-02	*	< LOD	< LOD	< LOD	< LOD	576
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	819
20-59 years	01-02	*	< LOD	< LOD	< LOD	< LOD	1105
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1178
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1322
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	678
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	672
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	952

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Alachlor

CAS No. 15972-60-8

General Information

Alachlor is a chloroacetanilide type herbicide with restricted usage for preemergent control of grasses and broadleaf weeds on agricultural cropland, including corn, soybeans, peanuts and other crops, and on non-crop land for general weed control. Since the late 1980s alachlor use has been declining. In 1993-1995, about 20-25% of the U.S. corn cropland was treated with alachlor. It is absorbed by plants and inhibits plant protein synthesis. Alachlor has a soil half-life of a few weeks. It is both metabolized in plants and degraded microbiologically in agricultural soils into as many as 19 metabolites and degradates. Alachlor and its degradates are leachable from agricultural soils and have been detected in watersheds of agricultural land including ground and surface waters (Battaglin et al., 2000; Hladik et al., 2005; Kolpin et al., 2000; USGS, 1999 and 2007; WHO, 2003). Alachlor is highly toxic to freshwater fish and slightly toxic to birds and some invertebrates, but shows little bioaccumulation.

General population exposure to alachlor may occur through consumption of contaminated food or drinking water. Estimated human intakes have been below recommended limits (U.S.EPA, 1998). Because it can be absorbed through skin, the dermal exposure route is potentially significant for applicators, formulators, and field workers. In animal studies, alachlor is quickly absorbed after oral doses and mostly excreted as metabolites within a week (IPCS, 1996; U.S.EPA, 1998; WHO, 2003). In animals, mercapturate conjugates were predominant metabolites, but another metabolic pathway can produce 2,6-diethylaniline and its reactive metabolite; the latter may account for some observed effects (Davison et al., 1994; Feng and Wratten, 1989; Jefferies et al., 1998). People exposed to alachlor will excrete alachlor mercapturate in their urine (Driskell et al., 1996), but this metabolite is not a marker of exposure to most plant metabolites or environmental degradates which are often more prevalent in the environment.

Human health effects from alachlor at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Alachlor has low potential for acute toxicity. In chronic animal testing, alachlor has demonstrated hepatotoxicity, hemosiderosis, and uveal degeneration, but has not shown developmental or reproductive toxicity in mammalian systems (U.S.EPA, 1998; WHO, 2003). Alachlor itself is not considered mutagenic, though positive genotoxic results are reported for several metabolites of alachlor (Brown et al., 1988; Hill et al., 1997; Tessier and Clark, 1995; U.S.EPA, 1998). Animal carcinogenicity studies have demonstrated tumors of the nasal turbinates, stomach, and thyroid only at either maximum tolerated doses or related to species-specific pathways (Heydens et al., 1999; IPCS, 1996; U.S.EPA, 1998; WHO, 2003). U.S.EPA considers alachlor to be a probable human carcinogen at high doses, but not likely at low doses. NTP and IARC do not have ratings regarding human carcinogenicity. Additional information about is available from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of alachlor mercapturate reflect recent exposure. Urinary levels of alachlor mercapturate were generally not detectable in the NHANES 2001-2002 subsample (CDC, 2005). In a study of applicators and workers exposed to alachlor, mean values of urinary concentrations of alachlor metabolites, as measured through conversion to deethylamine, ranged from 0.1 to 1.1 mg/L at various collection times (Sanderson et al., 1995). Hines et al. (2003) showed that 2.2% of a reference population had detectable alachlor equivalents by immunoassay in their urine, whereas 60% of applicators had detectable amounts.

Finding measurable amounts of alachlor mercapturate in the urine does not mean that the levels of alachlor mercapturate cause an adverse health effect. Biomonitoring studies on levels of alachlor mercapturate provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of alachlor than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Alachlor mercapturate

Metabolite of Alachlor

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1942
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	463
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	662
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	817
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	950
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	992
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	679
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	507
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	586

Limit of detection (LOD, see Data Analysis section) for Survey year 99-00 is 1.18.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Alachlor mercapturate (creatinine corrected)

Metabolite of Alachlor

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1942
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	463
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	662
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	817
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	950
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	992
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	679
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	507
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	586

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Atrazine

CAS No. 1912-24-9

General Information

Atrazine is a widely used chlorotriazine herbicide that acts against broadleaf and grassy weeds. Related chlorotriazine herbicides include simazine, propazine, and cyanazine, all of which act by inhibiting plant photosynthesis. Atrazine is applied pre- and post-emergence to agricultural land for crops such as corn and sorghum. It is also used as a non-selective herbicide. Atrazine was first registered as an herbicide in 1958. More than 70 million pounds have been applied annually in recent years, with about 75% of corn cropland receiving treatment. Atrazine has limited water solubility and is not tightly bound to soil, but it is leachable into ground and surface waters. In regions where atrazine is used, it is one of the more commonly detected pesticides in surface and ground waters (USGS, 2007). In soils, atrazine is slowly degraded to dealkylated products, which have half-lives of several months. Bacteria and plants can metabolize atrazine to hydroxyatrazine. Atrazine does not bioaccumulate. It has little toxicity in birds and moderate toxicity in some fish and aquatic invertebrates. Atrazine may alter the sexual development of frogs at environmental levels (Gammon et al., 2005; Hayes et al., 2002; U.S.EPA, 2003*a*).

For the general population, drinking water is an infrequent source of atrazine exposure, but estimates of seasonal intakes from drinking water in a small number of communities have exceeded the recommended limits (U.S.EPA, 2003*b*). As a result, atrazine use has progressively been restricted in an effort to reduce surface and ground water contamination. Applicators of atrazine may be exposed dermally and by inhalation. Atrazine is well absorbed orally, metabolized, and then eliminated in the urine over a few days (Bradway et al., 1982; Catenacci et al., 1993; Timchalk et al., 1990). In animals and humans, glutathione conjugation appeared to be the major route of biotransformation, resulting in atrazine mercapturate and N-dealkylation products (IPCS, 1996; U.S.EPA, 2003*b*). Atrazine mercapturate products accounted for a major proportion of human urinary metabolites (Lucas et al., 1993). The dealkylated chloroatrazine metabolites,

Urinary Atrazine mercapturate

Metabolite of Atrazine

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1878
	01-02	*	< LOD	< LOD	< LOD	< LOD	2477
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	449
	01-02	*	< LOD	< LOD	< LOD	< LOD	568
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	639
	01-02	*	< LOD	< LOD	< LOD	< LOD	809
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	790
	01-02	*	< LOD	< LOD	< LOD	< LOD	1100
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1162
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	959
	01-02	*	< LOD	< LOD	< LOD	< LOD	1315
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	676
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	498
	01-02	*	< LOD	< LOD	< LOD	< LOD	684
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	550
	01-02	*	< LOD	< LOD	< LOD	< LOD	918

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.791 and 0.3.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

particularly diaminochloroatrazine (the main dealkylated product), may mediate some effects of atrazine (Laws et al., 2003). Dealkylated metabolites from atrazine can also result from metabolism of other chlorotriazine pesticides, including simazine, propazine, and cyanazine. In addition to being human metabolites of atrazine, the dealkylated atrazine metabolites and hydroxyatrazine can occur in the environment from the breakdown of the parent chemical. Thus, detection of these dealkylated metabolites in a person's urine may also reflect exposure to these degradates in the environment.

Human health effects of atrazine at environmental doses or at biomonitored levels from environmental exposure are unknown. In mammalian studies, atrazine is rated as having low acute toxicity. Atrazine product formulations can be mild skin sensitizers and irritants. Chronic high dose toxicity observed in animals includes decreased body weight, myocardial muscle degeneration, liver toxicity, developmental ossification defects, impaired fertility, altered estrus cycles, increased pituitary weight, delayed onset of puberty, and reduced levels of luteinizing hormone, prolactin, and testosterone (Gillis et al., 1994; Laws et al., 2000 and 2003; Rayner et al., 2004; Stoker et al., 2000 and 2002; U.S.EPA, 2003*b*). Atrazine and the dealkylated chlorinated metabolites did not have estrogen receptor activity, but they reduced the pituitary secretion of luteinizing hormone and prolactin and also inhibited aromatase at high doses in some mammalian species (Cooper et al., 2000; Eldridge et al., 1994 and 1999; Gammon et al., 2005; Sanderson et al., 2002; Stevens et al., 1999). Estimated human exposures are thousands of times lower than doses that caused effects in animals (Gammon et al., 2005). Some human ecologic and epidemiologic studies of reproductive and cancer outcomes have shown either positive or no associations, but the effects are difficult to attribute due to lack of exposure markers or due to mixed chemical or pesticide exposures (ATSDR, 2003; Gammon et al., 2005; Sathiakumar and Delzell, 1997). Atrazine is not considered genotoxic. IARC considers atrazine not classifiable with respect to human carcinogenicity, and U.S.EPA considers atrazine unlikely to be a human carcinogen. Additional information is available from U.S. EPA at: http://www.epa.gov/pesticides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Urinary Atrazine mercapturate (creatinine corrected)

Metabolite of Atrazine

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1878
	01-02	*	< LOD	< LOD	< LOD	< LOD	2476
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	449
	01-02	*	< LOD	< LOD	< LOD	< LOD	568
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	639
	01-02	*	< LOD	< LOD	< LOD	< LOD	808
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	790
	01-02	*	< LOD	< LOD	< LOD	< LOD	1100
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1162
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	959
	01-02	*	< LOD	< LOD	< LOD	< LOD	1314
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	676
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	498
	01-02	*	< LOD	< LOD	< LOD	< LOD	683
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	550
	01-02	*	< LOD	< LOD	< LOD	< LOD	918

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

Urinary levels of atrazine mercapturate reflect recent exposure. In the NHANES 2001-2002 subsample, levels of atrazine mercapturate were generally not detectable (CDC, 2005). In small studies of Maryland residents in 1995-1996 (MacIntosh et al., 1999) and 83 Minnesota children with multiple urine collections during 1997 (Adgate et al., 2001), atrazine mercapturate was infrequently detected at the detection limit of < 1 µg/L. In a study of 60 farm worker children, atrazine was detected in only four children (Arcury et al., 2007). Through immunoassay atrazine equivalents (detected mostly as atrazine mercapturate), the urinary geometric mean levels for herbicide applicators in Ohio and Wisconsin were about 6 µg/L (Hines et al., 2003; Perry et al., 2000). The geometric mean of urinary atrazine mercapturate was 1.2 µg/L in 15 farmers studied several days after spraying the pesticide (Curwin et al., 2005). In a small number of field workers, urinary concentrations ranged from 5-1756 µg/L (Lucas et al., 1993).

Finding measurable amounts of atrazine mercapturate in urine does not mean that the levels of atrazine mercapturate cause an adverse health effect. Biomonitoring studies on levels of atrazine mercapturate provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of atrazine than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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2,4-Dichlorophenoxyacetic Acid

CAS No. 94-75-7

General Information

Widely used throughout the United States, the chlorophenoxy herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) controls broadleaf weeds in residential, agricultural, and aquatic environments. It was first registered with U.S.EPA in 1948. Similar to other chlorophenoxy herbicides, it acts as a plant growth hormone. At low levels, these herbicides can enhance plant growth, but at higher levels they are herbicidal. 2,4-D can be applied either as an aqueous salt or as oil-soluble esters, and it is often mixed with other chlorophenoxy acid herbicides (such as dicamba, MCPA, and mecoprop). As much as 62 million pounds of 2,4-D were used in the U.S. in 2001 (U.S.EPA, 2004). It is poorly bound in soils, with a half-life of several days to several weeks. It is rarely detected in ground waters (USGS, 2007). Acid and salt forms are much less toxic to fish and aquatic invertebrates than the ester forms.

General population exposure to 2,4-D may occur during residential applications, by direct contact with agricultural and residential areas after applications, and by consuming food or drinking water contaminated with 2, 4-D. Recent estimates of chronic intakes of 2,4-D have been below recommended intake limits (U.S.EPA, 2005). 2,4-D is rapidly absorbed via oral and inhalation routes. It is not well absorbed through the skin, although dermal exposure may be significant for herbicide manufacturing plant workers exposed to high concentrations of 2,4-D or exposed for prolonged periods. Once absorbed, 2,4-D is eliminated mostly unchanged in the urine with an elimination half-life ranging from 10 to 33 hours (Arnold et al., 1989; Kohli et al., 1974; Sauerhoff et al., 1977).

Human health effects from 2,4-D at low environmental doses or at biomonitored levels from low environmental exposures are unknown. 2,4-D has low acute toxicity. Intentional overdoses and unintentional high dose exposures to chlorophenoxy acid herbicides have resulted in weakness, headache, dizziness, nausea, abdominal pain, myotonia, hypotension, renal and hepatic injury, and delayed

Urinary 2,4-Dichlorophenoxyacetic acid

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	
	01-02	*	< LOD	.230 (<LOD-.320)	.690 (.560-.910)	1.27 (1.02-1.37)	
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	1.30 (<LOD-2.40)	
	01-02	*	< LOD	.310 (.210-.400)	.740 (.550-1.13)	1.55 (1.00-2.21)	
12-19 years	99-00	*	< LOD	< LOD	< LOD	1.10 (<LOD-1.60)	
	01-02	*	< LOD	.250 (<LOD-.420)	.690 (.440-1.16)	1.24 (.690-1.66)	
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	
	01-02	*	< LOD	.210 (<LOD-.310)	.690 (.540-.910)	1.27 (.930-1.49)	
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	1.10 (<LOD-1.80)	
	01-02	*	< LOD	.330 (.230-.490)	.930 (.680-1.22)	1.51 (1.27-2.08)	
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	
	01-02	*	< LOD	< LOD	.490 (.370-.660)	.890 (.670-1.22)	
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	
	01-02	*	< LOD	.260 (<LOD-.350)	.730 (.610-.910)	1.20 (.960-1.43)	
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	1.20 (<LOD-1.70)	
	01-02	*	< LOD	< LOD	.610 (.420-.890)	1.07 (.810-1.48)	
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	
	01-02	*	< LOD	.250 (<LOD-.410)	.760 (.560-1.10)	1.32 (1.05-2.03)	

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.952 and 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

neuropathy (Bradberry et al., 2004). The acid and salt forms of 2,4-D are eye irritants. Acute high doses administered to laboratory animals produced ataxia, myotonia, and evidence of histological injury to the kidneys, liver, thyroid, eyes, adrenals and gonads (NTP, 2006; U.S.EPA, 2005). 2,4-D does not have significant reproductive, developmental, or teratogenic effects in chronic rodent studies (Charles et al., 2001; IPCS, 1996; U.S.EPA 2005). Epidemiological studies have reported associations of several types of cancer, such as soft tissue sarcoma and non-Hodgkin's lymphoma, with the exposure to chlorophenoxy herbicides as defoliants or contaminated herbicides. It is unclear whether these associations are related to the chlorophenoxy herbicides, other exposures, or to contaminants in the herbicide formulations (specifically 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) (Garabrant and Philbert, 2002; IOM, 2003; IPCS, 1996; Pearce and McLean; 2005; U.S.EPA, 2005). 2,4-D was not found to be genotoxic or carcinogenic in animal studies (Garabrant and Philbert, 2002; IPCS, 1996; U.S.EPA, 2005). IARC considers the chlorophenoxyacetic acids group of chemicals as possibly carcinogenic to humans. Additional information is available from U.S.EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of 2,4-D reflect recent exposure. The 95th percentiles of the NHANES 1999-2000 and 2001-2002 subsamples were roughly similar to the 95th percentile values reported in a nonrandom subsample from NHANES III (1988-1994) (CDC, 2005; Hill et al., 1995). In previous samples of the U.S. population (Hill et al., 1995; Kutz et al., 1992), in small samples of children (Hill et al., 1989), and of adults and children (Baker et al., 2000), urinary 2,4-D levels were detectable in less than a quarter of the individuals studied.

2,4-D production plant workers and a few forestry workers spraying 2,4-D had urinary levels several hundred to several thousand times higher than the 95th percentiles of the NHANES subsamples (CDC, 2005; Frank et al., 1985; Kolmodin-Hedman and Erne, 1980; Knopp et al., 1994). Average post-application urinary levels of 2,4-D in farmers were more than 25-fold higher than the 95th percentiles in the NHANES 1999-2000 and 2001-2002 subsamples (Arbuckle et al., 2005; CDC, 2005). Post-application levels in farmers and home gardeners were dependent on

Urinary 2,4-Dichlorophenoxyacetic acid (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1977
	01-02	*	< LOD	.380 (<LOD-.410)	.670 (.610-.780)	1.08 (.930-1.26)	2412
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	1.32 (<LOD-2.24)	477
	01-02	*	< LOD	.490 (.380-.680)	1.13 (.820-1.35)	1.41 (1.27-1.73)	546
12-19 years	99-00	*	< LOD	< LOD	< LOD	.590 (<LOD-1.05)	677
	01-02	*	< LOD	.270 (<LOD-.380)	.480 (.330-.660)	.660 (.520-.920)	796
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	823
	01-02	*	< LOD	.380 (<LOD-.410)	.670 (.580-.790)	1.08 (.810-1.29)	1070
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	.670 (<LOD-1.16)	962
	01-02	*	< LOD	.340 (.270-.410)	.640 (.560-.790)	1.14 (.890-1.39)	1135
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1015
	01-02	*	< LOD	< LOD	.700 (.610-.780)	1.08 (.810-1.26)	1277
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	695
	01-02	*	< LOD	.350 (<LOD-.390)	.720 (.560-.850)	1.13 (.780-1.56)	659
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	.590 (<LOD-1.19)	520
	01-02	*	< LOD	< LOD	.440 (.340-.570)	.780 (.550-.980)	667
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	589
	01-02	*	< LOD	.410 (<LOD-.470)	.740 (.620-.890)	1.17 (.990-1.40)	892

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

the time since application, the amount of pesticide applied, the number of acres to which it was applied (Curwin et al., 2005), and the use of protective clothing or equipment (Arbuckle et al., 2005; Harris et al., 1992). In farm families, geometric mean urinary levels of 2,4-D were highest in the farmers who applied the 2,4-D; other family members had levels ranging only slightly higher than the 95th percentile levels in NHANES 1999-2000 and 2001-2002 subsamples (CDC, 2005; Mandel et al., 2005).

Finding a measurable amount of 2,4-D in urine does not mean that the level of the 2,4-D will result in an adverse health effect. Biomonitoring studies of 2,4-D in urine provide physicians and public health officials with reference values so that they can determine whether other people have been exposed to higher levels of 2,4-D than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Metolachlor

CAS No. 51218-45-2

General Information

Metolachlor is a chloroacetanilide type herbicide that is applied for preemergent control of grasses and broadleaf weeds on agricultural crop land, including corn, soybeans, sorghum and other crops, and on non-crop land for general weed control. It is absorbed by plants and inhibits plant protein synthesis. Metolachlor has a soil half-life of a few weeks to three months and is degraded microbiologically and photochemically to at least five different products. Metolachlor or its degradates can leach from soils and have been detected in watersheds of agricultural land, in both ground and surface waters (Battaglin et al., 1999; Gilliom, 2007; Hladik et al., 2005; Kolpin et al., 2000; USGS, 2007; WHO, 2003). Occasionally in the past, metolachlor levels in water have exceeded lifetime human health advisory levels (U.S.EPA, 1995). Metolachlor shows little potential to bioaccumulate but is moderately toxic to fish.

General population exposure may occur through the consumption of contaminated food or drinking water. Estimated human intakes have been below recommended limits (U.S.EPA, 1995). Metolachlor is well absorbed dermally, so applicators, formulators, and field workers may have significant exposures via this route. In animal studies, metolachlor was quickly absorbed after dermal or oral doses, and eliminated in urine and feces over two to three days (WHO, 2003). In animals, mercapturate conjugates were the predominant metabolites, but another metabolic pathway can produce 2-methyl-6-ethylaniline and its reactive metabolite which may account for observed effects (Coleman et al., 2000; Davison et al., 1994; Feng and Wratten, 1989; Jefferies et al., 1998). People exposed to metolachlor will excrete metolachlor mercapturate in their urine. This metabolite is not a marker of exposure to either plant metabolites or environmental degradates of metolachlor which can be present in the environment.

Human health effects from metolachlor at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Metolachlor has low potential for acute toxicity (U.S. EPA, 1995). Salivation, lacrimation, and convulsions were observed at lethal doses in animal studies. Metolachlor did not show developmental or reproductive toxicity in chronic animal studies, and it was not mutagenic in mammalian cells (U.S.EPA, 1995; WHO, 2003). U.S.EPA considers metolachlor to be a possible human carcinogen; NTP and IARC do not have ratings regarding human carcinogenicity. Additional information is available from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of metolachlor mercapturate reflect recent exposure. Urinary levels of metolachlor mercapturate were generally not detectable in the NHANES 2001-2002 subsample, though the 95th percentile for males was 0.200 µg/L (CDC, 2005). The geometric mean metolachlor mercapturate was 4.7 µg/L in the urine of farmers after they had sprayed metolachlor (Curwin et al., 2005). Hines et al. (2003) showed that 2.2% of a small reference population had detectable metolachlor equivalents by immunoassay in their urine, whereas 60% of applicators had detectable amounts.

Finding measurable amounts of metolachlor mercapturate in the urine does not mean that the levels of metolachlor mercapturate cause an adverse health effect. Biomonitoring studies on levels of metolachlor mercapturate provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels metolachlor than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Metolachlor mercapturate

Metabolite of Metolachlor

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	2538
Age group							
6-11 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	580
12-19 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	831
20-59 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1127
Gender							
Males	01-02	*	**< LOD**	**< LOD**	**< LOD**	**.200** (<LOD-.220)	1192
Females	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1346
Race/ethnicity							
Mexican Americans	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	679
Non-Hispanic blacks	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	701
Non-Hispanic whites	01-02	*	**< LOD**	**< LOD**	**< LOD**	**.200** (<LOD-.240)	957

Limit of detection (LOD, see Data Analysis section) for Survey year 01-02 is 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Metolachlor mercapturate (creatinine corrected)

Metabolite of Metolachlor

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	2537
Age group							
6-11 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	580
12-19 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	830
20-59 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1127
Gender							
Males	01-02	*	**< LOD**	**< LOD**	**< LOD**	**.440** (<LOD-.500)	1192
Females	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1345
Race/ethnicity							
Mexican Americans	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	679
Non-Hispanic blacks	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	700
Non-Hispanic whites	01-02	*	**< LOD**	**< LOD**	**< LOD**	**.670** (<LOD-.740)	957

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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2,4,5-Trichlorophenoxyacetic Acid

CAS No. 93-76-5

General Information

2,4,5-Trichlorophenoxyacetic acid (2,4,5-T) is a chlorophenoxy acid herbicide that is no longer registered for use in the United States. Chlorophenoxy herbicides act as plant growth hormones. At low levels, these herbicides can enhance plant growth, but higher levels are herbicidal. 2,4,5-T was once applied as either an aqueous salt or as an oil-soluble ester. Ester forms of 2,4,5-T and 2,4-D were used as defoliants in the Vietnam War (e.g., Agent Orange), and concern about contamination with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) led to the discontinuation of 2,4,5-T use as a herbicide in 1985. The half-life of 2,4,5-T in soil varies with conditions, ranging from several weeks to many months. 2,4,5-T degrades to 2,4,5-trichlorophenol and other degradates. 2,4,5-T has been rarely detected in ground waters (USGS, 2007).

Given the commercial unavailability of 2,4,5-T, the general population is unlikely to be exposed to it. Although 2,4,5-T is rapidly absorbed via oral and inhalation routes, it is not well absorbed through the skin. Once absorbed into the body, 2,4,5-T is eliminated mostly unchanged in the urine, with an elimination half-life of approximately 19 hours (Arnold et al., 1989; Kohli et al., 1974).

Human health effects from 2,4,5-T at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Intentional overdoses and unintentional high dose occupational exposures to chlorophenoxy acid herbicides have resulted in weakness, headache, dizziness, nausea, abdominal pain, myotonia, hypotension, renal and hepatic injury, and delayed neuropathy (Bradberry et al., 2004). Teratogenic and developmental effects have been reported in studies of multiple rodent strains treated with high doses of technical grade 2,4,5-T (Holson et al., 1992; Mohammad and St. Omer, 1986; Nelson et al., 1992). Epidemiological studies have reported associations of several types of cancer, such as soft tissue sarcoma and non-Hodgkin's lymphoma, with the exposure to chlorophenoxy herbicides as defoliants

Urinary 2,4,5-Trichlorophenoxyacetic acid

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1814
	01-02	*	< LOD	< LOD	< LOD	< LOD	2538
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	430
	01-02	*	< LOD	< LOD	< LOD	< LOD	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	618
	01-02	*	< LOD	< LOD	< LOD	< LOD	831
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	766
	01-02	*	< LOD	< LOD	< LOD	< LOD	1127
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	891
	01-02	*	< LOD	< LOD	< LOD	< LOD	1192
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	923
	01-02	*	< LOD	< LOD	< LOD	< LOD	1346
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	652
	01-02	*	< LOD	< LOD	< LOD	< LOD	679
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	483
	01-02	*	< LOD	< LOD	< LOD	< LOD	701
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	531
	01-02	*	< LOD	< LOD	< LOD	< LOD	957

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 1.2 and 0.1.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

or contaminated herbicides. It is unclear whether these associations are related to the chlorophenoxy herbicides, other exposures, or to contaminants in the herbicide formulations (specifically 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) (Garabrant and Philbert, 2002; IOM, 2003; IPCS, 1996; Pearce and McLean, 2005; U.S.EPA, 2004). 2,4,5-T itself is not mutagenic. IARC considers the chlorophenoxyacetic acids group of chemicals as possibly carcinogenic to humans. Additional information is available from U.S.EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of 2,4,5-T reflect recent exposure. In the NHANES 1999-2000 and 2001-2002 subsamples (CDC, 2005), urinary levels of 2,4,5-T were generally below the limit of detection, similar to results of NHANES II (1976-1980), in which urinary levels of 2,4,5-T also were below the limit of detection (Kutz et al., 1992). Mean urinary levels of 2,4,5-T measured after a day of exposure in a few asymptomatic herbicide applicators were 35,000 times higher than the detection limit for the NHANES 2001-2002 data (Kolmodin-Hedman and Erne, 1980).

Finding a measurable amount of 2,4,5-T does not mean that the level will result in an adverse health effect. Biomonitoring studies on 2,4,5-T in urine also provide physicians and public health officials with reference values so that they can determine whether other people have been exposed to higher levels of 2,4,5-T than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 2,4,5-Trichlorophenoxyacetic acid (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1814
	01-02	*	< LOD	< LOD	< LOD	< LOD	2537
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	430
	01-02	*	< LOD	< LOD	< LOD	< LOD	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	618
	01-02	*	< LOD	< LOD	< LOD	< LOD	830
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	766
	01-02	*	< LOD	< LOD	< LOD	< LOD	1127
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	891
	01-02	*	< LOD	< LOD	< LOD	< LOD	1192
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	923
	01-02	*	< LOD	< LOD	< LOD	< LOD	1345
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	652
	01-02	*	< LOD	< LOD	< LOD	< LOD	679
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	483
	01-02	*	< LOD	< LOD	< LOD	< LOD	700
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	531
	01-02	*	< LOD	< LOD	< LOD	< LOD	957

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Carbamate Insecticides

General Information

N-methyl carbamate insecticides (carbamates) have been widely used in the U.S. and throughout the world. In agricultural applications, the use of the carbamate insecticides has decreased, being replaced by pyrethroid and other insecticides. Carbamates have been used on residential lawns, ornamentals, in nurseries, and on golf courses. Carbamates do not persist in the environment and have a low potential for bioaccumulation. Some other chemical types of carbamates, thiocarbamates and dithiocarbamates, are used as herbicides and fungicides.

General population exposure to carbamates occurs during contact with residential uses and, less commonly, from ingesting contaminated foods. Agricultural workers can be exposed when they re-enter areas recently treated. Exposures of workers also can occur during the manufacture, formulation, or application of these chemicals. Carbamates can be absorbed through the skin, via inhalation, or by ingestion. Criteria for allowable levels of specific carbamates in food, the environment, and the workplace have been developed by the U.S. FDA, U.S. EPA, and OSHA, respectively.

Carbamate insecticides act by inhibiting acetylcholinesterase enzymes, leading to an increase of acetylcholine in the nervous system. At high doses, toxic symptoms include nausea, vomiting, cholinergic signs, weakness, paralysis, and seizures. The mechanism of toxicity of carbamate insecticides is similar to that of organophosphate pesticides; however, carbamate insecticides generally are reversible inhibitors of acetylcholinesterase activity, acting for a shorter time than organophosphate pesticides. Carbamate insecticides are rapidly eliminated from the body. Only two metabolites are measured in this *Report* (metabolites of carbofuran and propoxur), of the carbamate insecticides still used in the U.S.

Carbofuran

CAS No. 1563-66-2

General Information

Carbofuranphenol is a metabolite of four different carbamate insecticides: benfuracarb; carbofuran; carbosulfan; and furathiocarb. Only carbofuran is registered in the U.S. Carbofuran is a broad spectrum, restricted-use insecticide and nematicide applied to a variety of field, fruit, and vegetable crops for control of beetles, borers, nematodes, weevils, and similar pests. Recently, registered uses of carbofuran were cancelled except for the following: field corn; potatoes; pumpkins; sunflowers; pine seedlings; and spinach grown for seed (U.S.EPA, 2009). About 1 million pounds have been used annually (U.S.EPA, 2007). Carbofuran is not registered for use in residential settings or food-handling establishments. In soils of varying composition, carbofuran has a half-life ranging from one to three months. It can leach into ground waters, but it has been detected only infrequently in either surface or ground waters (Gilliom, 2007; USGS, 2007). Carbofuran is very highly toxic to fish and aquatic invertebrates, and it is highly toxic to birds where granular applications are used, but such applications have been restricted since 1991 (U.S.EPA, 2007).

General population exposure can occur through consumption of food contaminated with carbofuran. Because estimated acute intakes from some dietary components in young children may exceed recommended intake limits, the U.S.EPA is in the process of revoking current regulations that allow carbofuran residues in food (U.S.EPA, 2009). Pesticide handlers and applicators are at greater risk for exposure and a number of incidents of systemic poisoning have been reported. After absorption, carbofuran is metabolized to phenolic metabolites and 3-hydroxycarbofuran, which are quickly eliminated in the urine.

Human health effects from carbofuran at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Carbofuran was very highly acutely toxic in animal studies, causing effects related

Urinary Carbofuranphenol

Metabolite of Benfuracarb, Carbofuran, Carbosulfan, and Furathiocarb

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	.770 (<LOD-1.30)	1994
	01-02	*	< LOD	< LOD	< LOD	< LOD	2530
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	.450 (<LOD-2.20)	482
	01-02	*	< LOD	< LOD	< LOD	< LOD	578
12-19 years	99-00	*	< LOD	< LOD	< LOD	.570 (<LOD-1.20)	681
	01-02	*	< LOD	< LOD	< LOD	< LOD	827
20-59 years	99-00	*	< LOD	< LOD	< LOD	.840 (<LOD-1.50)	831
	01-02	*	< LOD	< LOD	< LOD	< LOD	1125
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	.740 (<LOD-1.50)	973
	01-02	*	< LOD	< LOD	< LOD	< LOD	1190
Females	99-00	*	< LOD	< LOD	< LOD	.840 (<LOD-1.50)	1021
	01-02	*	< LOD	< LOD	< LOD	< LOD	1340
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	.590 (<LOD-2.00)	1.90 (<LOD-5.10)	696
	01-02	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	.550 (<LOD-1.60)	521
	01-02	*	< LOD	< LOD	< LOD	< LOD	696
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	.740 (<LOD-1.50)	603
	01-02	*	< LOD	< LOD	< LOD	< LOD	953

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.4 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

to acetylcholinesterase enzyme inhibition. In contrast, carbofuranphenol is not an inhibitor of acetylcholinesterase enzymes. Carbofuran was not teratogenic, but high chronic doses in animals produced nonspecific developmental effects, such as reduced weight gain and pup survival (WHO, 2004). Testicular toxicity at subacute doses was reported in adult rats, rat pups, and dogs (Pant et al., 1995, 1997; WHO, 2004). Carbofuran was found not to be mutagenic or carcinogenic in animals (U.S.EPA, 2007). It is not rated by IARC with regard to human carcinogenicity. Additional information is available from U.S.EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary carbofuranphenol levels reflect recent exposure. The level of this metabolite in urine may reflect exposure to carbofuran or to carbofuranphenol as a degradation product in the environment or food. In representative subsamples from NHANES 1999-2000 and 2001-2002, most urinary levels of carbofuranphenol were below the limit of detection (CDC, 2005). In a nonrandom subsample from NHANES III (1988-1994), the 99th percentile level of carbofuranphenol was 2.1µg/L (Hill et al., 1995). In a previous study of U.S. farmers and their families, carbofuranphenol was detected in 6.7% of urine samples (Shealy et al., 1997); the 95th percentile value in that study was 0.73 µg/L. Urinary levels of carbofuranphenol in two applicators were three and sixfold higher than the detection limit for the NHANES 2003-2004 subsample (Petropoulou et al., 2006).

Finding a measurable amount of carbofuranphenol in urine does not mean that the level of carbofuranphenol causes an adverse health effect. Biomonitoring studies on levels of carbofuranphenol provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of carbofuran or related carbamates than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Carbofuranphenol (creatinine corrected)

Metabolite of Benfuracarb, Carbofuran, Carbosulfan, and Furathiocarb

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	**.780** (<LOD-1.00)	1994
	01-02	*	< LOD	< LOD	< LOD	< LOD	2529
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	**.990** (<LOD-2.80)	482
	01-02	*	< LOD	< LOD	< LOD	< LOD	578
12-19 years	99-00	*	< LOD	< LOD	< LOD	**.480** (<LOD-.850)	681
	01-02	*	< LOD	< LOD	< LOD	< LOD	826
20-59 years	99-00	*	< LOD	< LOD	< LOD	**.880** (<LOD-1.06)	831
	01-02	*	< LOD	< LOD	< LOD	< LOD	1125
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**.670** (<LOD-1.08)	973
	01-02	*	< LOD	< LOD	< LOD	< LOD	1190
Females	99-00	*	< LOD	< LOD	< LOD	**.880** (<LOD-1.13)	1021
	01-02	*	< LOD	< LOD	< LOD	< LOD	1339
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**.780** (<LOD-1.94)	**1.83** (<LOD-4.16)	696
	01-02	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**.700** (<LOD-1.08)	521
	01-02	*	< LOD	< LOD	< LOD	< LOD	695
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	**.740** (<LOD-.930)	603
	01-02	*	< LOD	< LOD	< LOD	< LOD	953

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Propoxur

CAS No. 114-26-1

General Information

2-Isopropoxyphenol is a metabolite of propoxur, a carbamate used to control ants, roaches, hornets, and similar pests in residential areas and around commercial food-handling establishments. Propoxur has also been used in pest strips and pet flea collars. Like several other pesticides, propoxur has been used outside the U.S. as a replacement for DDT in malaria vector control. Propoxur may remain in the environment for weeks to several months, longer than most carbamates (U.S.EPA, 1997*b*). Despite its mobility in soil and its potential for leaching into groundwater, propoxur has been rarely detected in U.S. surface or ground waters (Gilliom, 2007; USGS, 2007). Although propoxur is toxic to birds and aquatic life, ecologic exposures are unlikely due to current outdoor use restrictions.

General population exposure to propoxur through the diet is likely to be limited because of usage restrictions (U.S. EPA, 1997*a*). Estimated human intakes have been below recommended intake limits (U.S.EPA, 1997*b*). Pesticide applicators are likely to have the highest exposures. Propoxur can be absorbed through the skin, lungs, and gastrointestinal tract. Propoxur does not accumulate in blood or tissues and is eliminated rapidly from the body (Leenheers et al., 1992; WHO, 2003). In animal and human studies, 2-isopropoxyphenol was one of several urine metabolites (U.S.EPA, 1997*b*).

Human health effects from propoxur at low environmental doses or at biomonitored levels from low environmental exposures are unknown. In animal studies, propoxur has moderate acute toxicity consisting of anticholinesterase effects (U.S.EPA, 1997*b*). 2-Isopropoxyphenol does not inhibit acetylcholinesterase enzymes. Propoxur is not considered mutagenic, embryotoxic, or teratogenic (WHO, 2003). U.S. EPA considers propoxur to be a probable human carcinogen, based on bladder tumors in male rats (U.S. EPA, 1997*b*). The human carcinogenic potential of propoxur has not been evaluated by IARC or NTP. Additional information is available from U.S.EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary 2-isopropoxyphenol levels reflect recent exposure. The level of this metabolite in urine may reflect exposure to propoxur or to 2-isopropoxyphenol as a degradation product in the environment or food (U.S.EPA, 1997*b*). In the U.S. representative subsamples from NHANES 1999-2000 and 2001-2002, most 2-isopropoxyphenol levels in urine were below the limit of detection (CDC, 2005). In a nonrandom subsample from NHANES III (1988-1994), the 95th percentile level of 2-isopropoxyphenol was 1.7 µg/L (Hill et al., 1995). Higher urinary levels of 2-isopropoxyphenol have been measured in a few pesticide applicators, with a range of 45-306 µg/g creatinine (Hardt and Angerer, 1999).

Finding a measurable amount of 2-isopropoxyphenol in urine does not mean that the level of 2-isopropoxyphenol causes an adverse health effect. Biomonitoring studies on levels of 2-isopropoxyphenol provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of propoxur than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 2-Isopropoxyphenol

Metabolite of Propoxur

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1917
	01-02	*	< LOD	< LOD	< LOD	< LOD	2503
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	456
	01-02	*	< LOD	< LOD	< LOD	< LOD	574
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	655
	01-02	*	< LOD	< LOD	< LOD	< LOD	820
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	806
	01-02	*	< LOD	< LOD	< LOD	< LOD	1109
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	936
	01-02	*	< LOD	< LOD	< LOD	< LOD	1178
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	981
	01-02	*	< LOD	< LOD	< LOD	< LOD	1325
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	664
	01-02	*	< LOD	< LOD	< LOD	< LOD	677
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	500
	01-02	*	< LOD	< LOD	< LOD	< LOD	696
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	585
	01-02	*	< LOD	< LOD	< LOD	< LOD	931

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 1.1 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary 2-Isopropoxyphenol (creatinine corrected)

Metabolite of Propoxur

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1917
	01-02	*	< LOD	< LOD	< LOD	< LOD	2502
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	456
	01-02	*	< LOD	< LOD	< LOD	< LOD	574
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	655
	01-02	*	< LOD	< LOD	< LOD	< LOD	819
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	806
	01-02	*	< LOD	< LOD	< LOD	< LOD	1109
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	936
	01-02	*	< LOD	< LOD	< LOD	< LOD	1178
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	981
	01-02	*	< LOD	< LOD	< LOD	< LOD	1324
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	664
	01-02	*	< LOD	< LOD	< LOD	< LOD	677
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	500
	01-02	*	< LOD	< LOD	< LOD	< LOD	695
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	585
	01-02	*	< LOD	< LOD	< LOD	< LOD	931

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Organochlorine Pesticides

General Information

Organochlorine pesticides, an older class of pesticides, are effective against a variety of insects. These chemicals were introduced in the 1940s, and many of their uses have been cancelled or restricted by the U.S. EPA because of their environmental persistence and potential adverse effects on wildlife and human health. Many organochlorines are no longer used widely in the U.S., but other countries continue to use them. Hexachlorobenzene has been used primarily as a fungicide or biocide.

Organochlorine pesticides can enter the environment after pesticide applications, disposal of contaminated wastes into landfills, and releases from manufacturing plants that produce these chemicals. Some organochlorines are volatile, and some can adhere to soil or particles in the air. In aquatic systems, sediments adsorb organochlorines, which can then bioaccumulate in fish and other aquatic mammals. These chemicals are fat soluble, so they are found at higher concentrations in fatty foods. In the general population, diet is the main source of exposure, primarily through the ingestion of fatty foods such as dairy products and fish. Usage restrictions have been associated with a general decrease in serum organochlorine levels in the U.S. population and other developed countries (Hagmar et al., 2006; Kutz et al., 1991). Contaminated drinking water and air are usually minor exposure sources. Infants can be exposed through breast milk, and the fetus can be exposed *in utero* via the placenta. Workers can be exposed to organochlorines in the manufacture, formulation, or application of these chemicals. The FDA, U.S. EPA, and OSHA have developed standards for allowable levels of certain organochlorines in foods, the environment, and the workplace, respectively. Attributing human health effects to specific organochlorine chemicals is difficult because exposure to multiple organochlorine chemicals occurs often and these chemicals may have similar actions.

The table shows selected parent organochlorines and their metabolites that can be measured in serum or urine. Measurements of these chemicals can reflect either recent or cumulative exposures, or both. Some of the metabolites can be produced from more than one pesticide. The level of a metabolite in a person's blood or urine may indicate exposure to the parent pesticide as well as to the metabolite itself.

Organochlorine Pesticides and Metabolites in this *Report*

Organochlorine Pesticide (CAS number)	**Serum pesticide or metabolite(s)** (CAS number)	**Urinary pesticide or metabolite(s)** (CAS number)
Aldrin (309-00-02)	Aldrin (309-00-02) Dieldrin (60-57-1)	
Chlordane (12789-03-6)	Oxychlordane (27304-13-8) *trans*-Nonachlor (3734-49-4)	
Dichlorodiphenyltrichloroethanes	*p,p'*-DDT (50-29-3) *p,p'*-DDE (72-55-9) *o,p'*-DDT (789-02-6)	
Dieldrin (60-57-1)	Dieldrin (60-57-1)	
Endrin (72-20-8)	Endrin (72-20-8)	
Heptachlor (76-44-8)	Heptachlor epoxide (1024-57-3)	
Hexachlorobenzene (118-74-1)	Hexachlorobenzene (118-74-1)	Pentachlorophenol (87-86-5) 2,4,6-Trichlorophenol (88-06-2) 2,4,5-Trichlorophenol (95-95-4)
Hexachlorocyclohexanes	*beta*-Hexachlorocyclohexane (319-85-7) *gamma*-Hexachlorocyclohexane (58-89-9)	Pentachlorophenol (87-86-5) 2,4,6-Trichlorophenol (88-06-2) 2,4,5-Trichlorophenol (95-95-4)
Mirex (2385-85-5)	Mirex (2385-85-5)	
2,4,5-Trichlorophenol (95-95-4) 2,4,6-Trichlorophenol (88-06-2)		2,4,5-Trichlorophenol (95-95-4) 2,4,6-Trichlorophenol (88-06-2)

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Kutz FW, Wood PH, Bottimore DP. Organochlorine pesticides and polychlorinated biphenyls in human adipose tissue. Rev Environ Contam Toxicol 1991;120:1-82.

Aldrin

CAS No. 309-00-02

Dieldrin

CAS No. 60-57-1

Also a Metabolite of Aldrin

General Information

Aldrin and dieldrin are no longer produced or used in the U.S. From the 1950s to 1970, both chemicals were applied mainly as a soil insecticide or seed dressing for food and commodity crops. Dieldrin was also used for mothproofing clothes and carpets. In tropical countries, dieldrin was used as a residual spray in residential dwellings to control vector-borne diseases such as malaria. The U.S. EPA cancelled agricultural uses of both pesticides in 1970; termiticide uses were cancelled in 1987. Aldrin is readily converted to dieldrin in the environment and in plants that take up the chemical. Aldrin volatilizes after agricultural soil applications or is converted to dieldrin, which volatilizes more slowly. These chemicals persist in the environment and bioaccumulate in foods (Jorgenson 2001; USGS, 2007). Aldrin is rarely detected in plants or animal tissues, but dieldrin has been detected in meats, dairy products, and in crops grown in soils that have been contaminated, usually by application, manufacturing, or disposal.

General population exposure to these chemicals occurs through the diet, and detection of dieldrin residue in foods has decreased over time (FDA, 2008). Inhalation exposure may occur among people living in residences where aldrin was applied historically as a pesticide. Aldrin and dieldrin are absorbed following ingestion, inhalation, and dermal application. After absorption, aldrin is metabolized to dieldrin so rapidly that aldrin is rarely detected. Dieldrin accumulates in fatty tissues, and its metabolites are excreted in bile and feces (ATSDR, 2002). It is also excreted in breast milk and can cross the placenta. The elimination half-life of dieldrin is approximately 1 year (IPCS, 1989; Jorgenson 2001).

Human health effects from aldrin and dieldrin at low environmental doses or at biomonitored levels from low environmental exposures are unknown. At high doses, aldrin and dieldrin block inhibitory neurotransmitters in the central nervous system (Narahashi et al., 1992). This blocking action can cause abnormal excitation of the brain, leading to symptoms such as headache, confusion, muscle

Serum Aldrin (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2275
	03-04	*	< LOD	< LOD	< LOD	< LOD	1946
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	< LOD	< LOD	< LOD	588
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1519
	03-04	*	< LOD	< LOD	< LOD	< LOD	1358
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1057
	03-04	*	< LOD	< LOD	< LOD	< LOD	946
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1218
	03-04	*	< LOD	< LOD	< LOD	< LOD	1000
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	559
	03-04	*	< LOD	< LOD	< LOD	< LOD	456
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	512
	03-04	*	< LOD	< LOD	< LOD	< LOD	485
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1045
	03-04	*	< LOD	< LOD	< LOD	< LOD	881

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 5.94 and 7.8.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

twitching, nausea, vomiting, and seizures. When fed to experimental animals, both aldrin and dieldrin caused liver enlargement and liver tumors; dieldrin at higher doses caused irritability, tremors, and occasionally, seizures (Smith, 1991). When dieldrin was fed to pregnant rodents, the offspring had altered CNS neurotransmitter levels (Sanchez-Ramos et al., 1998) and behavioral changes (Carlson and Rosellini, 1987). Studies done *in vitro* showed that dieldrin binds to estrogen receptors (Soto et al., 1995), but no estrogenic effect was noted in a study that used cultured cells (Tully et al., 2000). Epidemiologic and animal studies have not conclusively associated dieldrin exposure with risk for developing Parkinson's disease (Corrigan et al., 2000; Kanthasamy et al., 2005; Li et al., 2005).

The U.S. EPA has established environmental standards for aldrin and dieldrin, and the FDA monitors foods for pesticide residues. OSHA has established workplace exposure standards for aldrin and dieldrin. IARC has determined that aldrin and dieldrin are not classifiable with regard to human carcinogenicity. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

In the NHANES 2001-2002 and 2003-2004 subsamples, serum aldrin levels were below the limit of detection, similar to results in a subsample of NHANES II (1976-1980) (Stehr-Green, 1989). Levels of aldrin also were not detectable in 1996-1997 pooled samples from New Zealand adults (Bates et al., 2004).

Serum dieldrin levels at the 95th percentile in NHANES 2001-2002 and 2003-2004 subsamples were approximately ten times lower than the corresponding percentile measured in NHANES II (1976-1980), in which only 10.6% of the subsample had dieldrin levels above the limit of detection (Stehr-Green 1989). The median level in pooled samples from New Zealand adults obtained in 1996-1997 was generally similar to the 90th percentile for adults in this *Report* (Bates et al., 2004). In samples obtained between 1973 and 1991 from Norwegian women, the median serum dieldrin level was generally similar to the 90th percentile for females in this *Report* (Ward et al., 2000). Danish women whose serum was collected in 1976 had a median dieldrin level near the 95th percentile for females in this *Report* (Hoyer et al., 1998). In a study of pesticide applicators with occupational exposure to aldrin, median levels of dieldrin were more than thirtyfold higher than the 95th percentile

Serum Aldrin (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2275
	03-04	*	< LOD	< LOD	< LOD	< LOD	1946
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	< LOD	< LOD	< LOD	588
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1519
	03-04	*	< LOD	< LOD	< LOD	< LOD	1358
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1057
	03-04	*	< LOD	< LOD	< LOD	< LOD	946
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1218
	03-04	*	< LOD	< LOD	< LOD	< LOD	1000
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	559
	03-04	*	< LOD	< LOD	< LOD	< LOD	456
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	512
	03-04	*	< LOD	< LOD	< LOD	< LOD	485
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1045
	03-04	*	< LOD	< LOD	< LOD	< LOD	881

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum Dieldrin (lipid adjusted)

Also a Metabolite of Aldrin

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**15.3** (14.5-17.4)	**20.3** (18.7-22.4)	2159
	03-04	*	< LOD	**9.00** (8.40-9.90)	**14.4** (12.1-16.4)	**19.0** (15.8-24.2)	1952
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	716
	03-04	*	< LOD	< LOD	< LOD	**9.10** (<LOD-16.4)	587
20 years and older	01-02	*	< LOD	**10.5** (<LOD-11.6)	**16.6** (15.1-18.2)	**21.3** (19.1-24.0)	1443
	03-04	*	< LOD	**9.50** (8.80-10.4)	**14.9** (12.8-17.0)	**19.5** (16.0-25.7)	1365
Gender							
Males	01-02	*	< LOD	< LOD	**15.7** (14.4-18.7)	**20.3** (18.6-24.0)	1007
	03-04	*	< LOD	**9.30** (8.40-10.8)	**15.1** (13.1-19.1)	**21.9** (14.9-38.5)	954
Females	01-02	*	< LOD	< LOD	**15.3** (13.4-17.2)	**19.8** (18.0-21.6)	1152
	03-04	*	< LOD	**8.70** (7.80-9.50)	**12.8** (11.2-15.4)	**16.9** (13.9-22.4)	998
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	**11.7** (<LOD-15.1)	**15.4** (12.7-19.1)	539
	03-04	*	< LOD	< LOD	**10.8** (9.00-14.1)	**14.0** (10.6-24.1)	456
Non-Hispanic blacks	01-02	*	< LOD	< LOD	**15.0** (11.8-19.1)	**20.6** (15.8-25.2)	484
	03-04	*	< LOD	**8.80** (<LOD-10.1)	**13.0** (10.5-15.8)	**15.9** (13.3-21.5)	487
Non-Hispanic whites	01-02	*	< LOD	< LOD	**15.6** (14.8-17.8)	**21.1** (18.9-23.6)	980
	03-04	*	< LOD	**9.30** (8.60-10.2)	**14.9** (12.5-17.5)	**19.7** (15.6-33.4)	885

Limits of detection (LOD, see Data Analysis section) for survey years 01-02 and 03-04 are 10.5 and 7.8.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum Dieldrin (whole weight)

Also a Metabolite of Aldrin

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**.110** (.100-.120)	**.150** (.130-.170)	2159
	03-04	*	< LOD	**.059** (.054-.064)	**.098** (.083-.112)	**.138** (.109-.177)	1952
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	716
	03-04	*	< LOD	< LOD	< LOD	**.048** (<LOD-.093)	587
20 years and older	01-02	*	< LOD	**.070** (<LOD-.080)	**.120** (.110-.130)	**.160** (.140-.180)	1443
	03-04	*	< LOD	**.062** (.056-.069)	**.102** (.088-.117)	**.139** (.112-.182)	1365
Gender							
Males	01-02	*	< LOD	< LOD	**.120** (.100-.130)	**.160** (.130-.190)	1007
	03-04	*	< LOD	**.064** (.054-.075)	**.109** (.084-.138)	**.147** (.108-.242)	954
Females	01-02	*	< LOD	< LOD	**.100** (.090-.110)	**.140** (.120-.160)	1152
	03-04	*	< LOD	**.055** (.049-.060)	**.089** (.077-.100)	**.110** (.096-.147)	998
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	**.090** (<LOD-.100)	**.120** (.090-.140)	539
	03-04	*	< LOD	< LOD	**.077** (.062-.116)	**.113** (.073-.158)	456
Non-Hispanic blacks	01-02	*	< LOD	< LOD	**.090** (.070-.110)	**.130** (.090-.190)	484
	03-04	*	< LOD	**.053** (<LOD-.058)	**.080** (.063-.101)	**.103** (.080-.149)	487
Non-Hispanic whites	01-02	*	< LOD	< LOD	**.110** (.100-.130)	**.150** (.130-.180)	980
	03-04	*	< LOD	**.062** (.054-.070)	**.103** (.086-.124)	**.139** (.109-.202)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

in the NHANES 2001-2002 and 2003-2004 subsamples (Edwards and Priestly 1994).

Finding a measurable amount of aldrin or dieldrin in serum does not mean that the level of aldrin or dieldrin causes an adverse health effect. Biomonitoring studies on levels of aldrin and dieldrin provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of aldrin or dieldrin than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Chlordane

CAS No. 57-74-9

Heptachlor

CAS No. 76-44-8

General Information

Chlordane and heptachlor are structurally related organochlorine pesticides and were used in the U.S. from the early 1950's until the mid-1980's. As a result of the manufacturing process, the technical grade product of each chemical contains 10%-20% of the other chemical, in addition to trace amounts of numerous other related compounds (ATSDR, 2007). Technical grade chlordane had contained 7% *trans*-nonachlor. Chlordane is not currently produced or used in the U.S. Since 1992, heptachlor use has been limited to treatment of fire ants near power transformers. Until 1988, chlordane was used to kill termites and other insects on agricultural crops, lawns, buildings, and in soil. Heptachlor was used as a soil and seed treatment and for termite control in and around buildings until 1988. Both pesticides are persistent in soils and sediments and have been detected in water from agricultural run-off and near production and disposal facilities (ATSDR, 1994, 2007). Heptachlor and chlordane are somewhat volatile and may be detected in the air and dust of buildings long after treatment for termite or insect control (Whitemore et al., 1994).

Heptachlor and chlordane and their metabolites bioaccumulate in fatty animal tissues. Consequently, foods high in fat such as meat, fish, and dairy products are the usual sources of exposure to these chemicals in the general population. Both of these chemicals and their metabolites can cross the placenta and are excreted into breast milk, which results in exposure to the fetus and nursing infant

Serum Oxychlordane (lipid adjusted)

Metabolite of Chlordane

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**20.8** (17.8-23.0)	**34.4** (30.5-38.6)	**44.8** (40.2-49.6)	1661
	01-02	**11.4** (<LOD-12.5)	**11.1** (<LOD-12.5)	**21.7** (19.3-24.4)	**36.4** (31.5-41.4)	**49.7** (42.0-61.2)	2249
	03-04	**9.37** (8.69-10.1)	**10.3** (9.20-11.0)	**18.0** (16.8-20.1)	**29.0** (26.8-32.1)	**37.7** (34.8-43.8)	1978
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	663
	01-02	*	< LOD	< LOD	< LOD	**11.5** (<LOD-12.6)	752
	03-04	*	< LOD	< LOD	**9.20** (<LOD-11.5)	**11.5** (8.10-18.9)	595
20 years and older	99-00	*	< LOD	**23.3** (21.0-25.9)	**37.7** (32.3-43.5)	**47.7** (43.1-50.8)	998
	01-02	**12.9** (11.7-14.3)	**13.3** (11.4-14.9)	**23.9** (21.2-26.7)	**38.5** (33.4-45.9)	**53.1** (44.1-65.9)	1497
	03-04	**10.6** (9.82-11.5)	**11.4** (10.6-12.4)	**19.9** (17.9-21.5)	**31.3** (28.8-33.2)	**39.2** (36.5-44.8)	1383
Gender							
Males	99-00	*	< LOD	**18.1** (16.1-19.6)	**31.3** (25.9-38.2)	**42.4** (35.3-49.6)	793
	01-02	**11.1** (<LOD-12.6)	**11.1** (<LOD-12.6)	**20.6** (16.6-24.9)	**33.1** (27.5-43.8)	**48.1** (40.2-56.9)	1049
	03-04	**9.10** (8.20-10.1)	**9.90** (8.30-11.2)	**17.1** (15.6-18.4)	**27.6** (25.3-32.2)	**36.0** (32.7-39.2)	963
Females	99-00	*	< LOD	**22.3** (20.1-25.9)	**36.9** (31.5-40.3)	**46.2** (39.1-51.8)	868
	01-02	**11.7** (10.7-12.7)	**11.0** (<LOD-12.9)	**23.1** (20.7-25.0)	**37.5** (34.5-42.1)	**52.8** (42.7-70.0)	1200
	03-04	**9.63** (8.89-10.4)	**10.6** (9.10-11.3)	**20.1** (17.4-21.7)	**30.3** (27.5-32.7)	**41.9** (36.3-45.5)	1015
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**16.3** (<LOD-19.9)	**28.9** (18.8-42.0)	**39.9** (26.8-61.0)	628
	01-02	*	< LOD	**13.9** (11.0-18.4)	**27.2** (21.0-33.1)	**37.9** (29.9-42.0)	557
	03-04	*	< LOD	**12.8** (10.1-15.8)	**22.9** (15.8-31.4)	**31.4** (22.4-51.6)	462
Non-Hispanic blacks	99-00	*	< LOD	**18.7** (<LOD-32.2)	**39.9** (26.5-47.3)	**48.6** (43.5-65.5)	350
	01-02	**11.7** (<LOD-13.6)	< LOD	**22.8** (17.2-28.3)	**41.4** (30.6-53.7)	**56.5** (41.8-73.5)	501
	03-04	**8.74** (<LOD-10.2)	**8.70** (<LOD-10.6)	**18.9** (15.9-21.5)	**35.1** (25.4-40.2)	**44.2** (37.7-56.8)	493
Non-Hispanic whites	99-00	*	< LOD	**21.8** (18.6-24.6)	**34.2** (28.9-40.9)	**44.0** (37.2-49.8)	559
	01-02	**12.1** (11.0-13.3)	**11.8** (10.5-13.9)	**23.0** (20.1-25.7)	**37.5** (31.6-45.1)	**52.2** (41.0-67.4)	1031
	03-04	**10.2** (9.36-11.1)	**11.2** (10.0-12.1)	**19.7** (17.2-21.7)	**30.3** (26.8-33.6)	**37.7** (34.3-45.5)	898

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 14.5, 10.5, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

(Dallaire et al., 2002; Rogan, 1996; Takahashi et al., 1981). Chlordane and heptachlor are absorbed after oral, dermal, and inhalation exposure. Chlordane is metabolized primarily to oxychlordane and to a lesser extent, to heptachlor. The major metabolite of heptachlor is heptachlor epoxide, which is also persistent in the body (ATSDR, 2007). Elimination of all these chemicals from the body occurs over months to years, and breast milk is a major excretion route in lactating women.

Human health effects from either chlordane or heptachlor at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Acute, high doses of either chlordane or heptachlor block inhibitory neurotransmitters and result in central nervous system toxicity, characterized by seizures and paralysis. In laboratory animal studies, chronic doses of heptachlor have produced liver enlargement and injury; both chlordane and heptachlor induced hepatic cytochrome P450 enzymes and increased the incidence of liver tumors (NTP, 1977*a*, 1977*b*; Smith, 1991). Chronic feeding studies with either chlordane or heptachlor have demonstrated reduced fertility, neonatal mortality, and alterations in immune function of offspring. Subtle neurodevelopmental effects have been observed rodents after prenatal exposure to heptachlor (IPCS, 2006). Epidemiologic studies have not demonstrated teratogenic or developmental effects (Baker et al., 1991; Le Marchand et al., 1986). No clear evidence of excessive cancer rates was demonstrated in human epidemiologic studies (ATSDR, 2007; IARC, 2001; Shindell and Ulrich, 1986). IARC considers chlordane and heptachlor as possibly carcinogenic to humans. OSHA has established occupational exposure criteria, and NIOSH and ACGIH have recommended workplace exposure levels for each pesticide. The U.S. EPA has established environmental criteria for chlordane and heptachlor, and the U.S. FDA established allowable residues of chlordane, heptachlor, and heptachlor epoxide in foods and bottled water. Information

Serum Oxychlordane (whole weight)

Metabolite of Chlordane

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	.140 (.120-.150)	.260 (.200-.290)	.310 (.290-.340)	1661
	01-02	.070 (<LOD-.077)	.070 (<LOD-.080)	.140 (.130-.160)	.250 (.220-.300)	.350 (.290-.440)	2249
	03-04	.057 (.053-.062)	.063 (.058-.068)	.119 (.106-.133)	.204 (.189-.213)	.269 (.246-.291)	1978
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	663
	01-02	*	< LOD	< LOD	< LOD	.060 (<LOD-.070)	752
	03-04	*	< LOD	< LOD	.047 (<LOD-.063)	.066 (.048-.092)	595
20 years and older	99-00	*	< LOD	.150 (.140-.180)	.280 (.230-.300)	.330 (.300-.400)	998
	01-02	.082 (.074-.091)	.080 (.070-.090)	.160 (.140-.180)	.270 (.230-.320)	.370 (.310-.450)	1497
	03-04	.067 (.061-.073)	.073 (.066-.079)	.130 (.115-.146)	.210 (.203-.227)	.286 (.258-.320)	1383
Gender							
Males	99-00	*	< LOD	.120 (.100-.140)	.220 (.180-.280)	.300 (.260-.340)	793
	01-02	.069 (<LOD-.079)	.070 (<LOD-.080)	.130 (.120-.160)	.230 (.190-.300)	.320 (.250-.430)	1049
	03-04	.056 (.050-.063)	.063 (.055-.076)	.115 (.100-.126)	.189 (.168-.207)	.258 (.216-.302)	963
Females	99-00	*	< LOD	.140 (.130-.170)	.270 (.200-.310)	.320 (.290-.400)	868
	01-02	.071 (.065-.077)	.070 (<LOD-.080)	.150 (.130-.160)	.260 (.230-.310)	.370 (.280-.510)	1200
	03-04	.058 (.053-.064)	.063 (.057-.068)	.126 (.104-.146)	.208 (.199-.231)	.286 (.245-.331)	1015
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	.100 (<LOD-.130)	.210 (.130-.320)	.290 (.190-.410)	628
	01-02	*	< LOD	.100 (.070-.130)	.200 (.150-.240)	.280 (.210-.360)	557
	03-04	*	< LOD	.083 (.066-.104)	.149 (.108-.230)	.230 (.148-.373)	462
Non-Hispanic blacks	99-00	*	< LOD	.110 (<LOD-.170)	.240 (.170-.290)	.320 (.240-.430)	350
	01-02	.066 (<LOD-.077)	< LOD	.130 (.090-.170)	.260 (.180-.350)	.350 (.240-.560)	501
	03-04	.049 (<LOD-.057)	.050 (<LOD-.062)	.112 (.087-.136)	.225 (.165-.287)	.315 (.253-.348)	493
Non-Hispanic whites	99-00	*	< LOD	.140 (.120-.170)	.270 (.200-.300)	.320 (.280-.380)	559
	01-02	.075 (.068-.083)	.080 (.070-.090)	.150 (.130-.170)	.250 (.220-.310)	.370 (.280-.450)	1031
	03-04	.063 (.058-.070)	.070 (.063-.077)	.128 (.110-.148)	.207 (.190-.223)	.271 (.242-.315)	898

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

about external exposure (i.e., environmental levels) and health effects of chlordane and heptachlor is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html. A recent assessment of heptachlor is available at: http://www.inchem.org/documents/cicads/cicads/cicad70.htm#ref.

Biomonitoring Information

Serum oxychlordane and *trans*-nonachlor levels in NHANES 1999-2000, 2001-2002, and 2003-2004 subsamples were comparable to levels measured in Swedish women from 1996-1997 (Glynn et al., 2003). In serum samples obtained in between 1994 and1997 from Inuit women in different Arctic countries, the reported oxychlordane and *trans*-nonachlor geometric mean levels from Canada and Greenland groups were about threefold to fivefold higher than among females in this *Report* (van Oostdam et al., 2004). A small sample of Polish women had mean levels of oxychlordane and *trans*-nonachlor that were about fivefold lower than in females in the NHANES 2001-2002 subsample (Jaraczweska et al., 2006). Serum *trans*-nonachlor levels among females in the NHANES 1999-2001 subsample were about one half the levels obtained between 1994 and 1996 from women in New York (Wolff et al., 2000).

Levels of heptachlor epoxide among females in this *Report* were approximately one tenth of the corresponding 90th percentile for a cohort of pregnant women in California studied from 1963 to 1967 (James et al., 2002). Two episodes (one each in Arkansas and Hawaii) of inadvertent heptachlor contamination of dairy cattle feed occurred in the early-to-mid 1980's, resulting in human exposure to heptachlor epoxide that was excreted into the milk. For the exposed persons drinking milk in the Arkansas episode, mean serum heptachlor epoxide and oxychlordane levels were about sevenfold and threefold higher, respectively, than the 90th percentile values of NHANES 1999-2000 (Stehr-Green et al., 1988). In the Hawaii episode, the mean serum heptachlor epoxide and oxychlordane levels were more than twice as high, respectively, than the 90th percentile values of NHANES 1999-2000 (Baker, 1993).

Finding a measurable amount of oxychlordane, *trans*-nonachlor, or heptachlor epoxide in serum does not mean that the level of oxychlordane, *trans*-nonachlor, or heptachlor epoxide causes an adverse health effect. Biomonitoring studies on levels of oxychlordane, *trans*-nonachlor, and heptachlor epoxide provide physicians and public health officials with reference ranges so that they can determine whether people have been exposed to higher levels of heptachlor and chlordane than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum Heptachlor epoxide (lipid adjusted)

Metabolite of Heptachlor

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**15.4** (<LOD-19.8)	**24.0** (15.1-38.8)	1589
	01-02	*	< LOD	< LOD	**14.8** (13.0-17.8)	**21.8** (18.2-27.3)	2259
	03-04	*	< LOD	< LOD	**13.4** (11.1-15.9)	**18.9** (15.9-23.0)	1963
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	638
	01-02	*	< LOD	< LOD	< LOD	< LOD	741
	03-04	*	< LOD	< LOD	< LOD	< LOD	592
20 years and older	99-00	*	< LOD	< LOD	**17.8** (<LOD-23.9)	**27.1** (16.8-46.1)	951
	01-02	*	< LOD	< LOD	**15.7** (13.7-18.8)	**23.1** (19.1-29.1)	1518
	03-04	*	< LOD	**8.20** (<LOD-9.50)	**14.5** (11.6-17.6)	**20.6** (16.8-24.0)	1371
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**19.6** (<LOD-27.2)	760
	01-02	*	< LOD	< LOD	**13.9** (12.0-17.8)	**20.8** (15.9-25.3)	1047
	03-04	*	< LOD	< LOD	**13.4** (11.2-16.4)	**18.6** (16.6-21.3)	956
Females	99-00	*	< LOD	< LOD	**18.2** (<LOD-25.2)	**27.7** (16.0-54.3)	829
	01-02	*	< LOD	< LOD	**15.6** (13.3-18.2)	**23.2** (18.9-29.8)	1212
	03-04	*	< LOD	< LOD	**13.5** (11.0-16.8)	**19.6** (14.8-24.5)	1007
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**15.3** (<LOD-25.6)	**22.2** (<LOD-62.3)	598
	01-02	*	< LOD	< LOD	**13.2** (<LOD-16.3)	**16.8** (13.8-23.1)	553
	03-04	*	< LOD	< LOD	**10.6** (8.10-13.5)	**13.7** (10.9-16.5)	460
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**19.5** (<LOD-32.4)	336
	01-02	*	< LOD	< LOD	**14.6** (11.7-19.0)	**21.5** (18.2-27.3)	503
	03-04	*	< LOD	< LOD	**13.5** (10.1-16.8)	**18.6** (12.7-25.2)	490
Non-Hispanic whites	99-00	*	< LOD	< LOD	**16.5** (<LOD-21.8)	**26.4** (<LOD-54.3)	539
	01-02	*	< LOD	< LOD	**15.3** (13.0-19.6)	**22.8** (18.9-29.8)	1041
	03-04	*	< LOD	**7.90** (<LOD-9.40)	**14.0** (11.2-17.6)	**20.4** (15.8-24.5)	888

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 14.6, 10.5, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum Heptachlor epoxide (whole weight)

Metabolite of Heptachlor

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	.110 (<LOD-.140)	.180 (.110-.220)	1589
	01-02	*	< LOD	< LOD	.100 (.090-.120)	.150 (.130-.180)	2259
	03-04	*	< LOD	< LOD	.094 (.076-.108)	.128 (.108-.161)	1963
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	638
	01-02	*	< LOD	< LOD	< LOD	< LOD	741
	03-04	*	< LOD	< LOD	< LOD	< LOD	592
20 years and older	99-00	*	< LOD	< LOD	.130 (<LOD-.170)	.190 (.130-.270)	951
	01-02	*	< LOD	< LOD	.110 (.090-.140)	.170 (.140-.190)	1518
	03-04	*	< LOD	.057 (<LOD-.063)	.101 (.082-.116)	.135 (.113-.173)	1371
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	.150 (<LOD-.180)	760
	01-02	*	< LOD	< LOD	.100 (.090-.120)	.150 (.110-.180)	1047
	03-04	*	< LOD	< LOD	.094 (.077-.111)	.126 (.106-.149)	956
Females	99-00	*	< LOD	< LOD	.120 (<LOD-.190)	.200 (.120-.310)	829
	01-02	*	< LOD	< LOD	.100 (.090-.130)	.170 (.130-.200)	1212
	03-04	*	< LOD	< LOD	.096 (.071-.108)	.133 (.107-.173)	1007
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	.100 (<LOD-.170)	.170 (<LOD-.380)	598
	01-02	*	< LOD	< LOD	.090 (<LOD-.110)	.120 (.100-.240)	553
	03-04	*	< LOD	< LOD	.069 (.053-.097)	.098 (.074-.113)	460
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	.110 (<LOD-.200)	336
	01-02	*	< LOD	< LOD	.090 (.070-.110)	.130 (.100-.180)	503
	03-04	*	< LOD	< LOD	.087 (.067-.104)	.110 (.090-.157)	490
Non-Hispanic whites	99-00	*	< LOD	< LOD	.120 (<LOD-.170)	.180 (<LOD-.310)	539
	01-02	*	< LOD	< LOD	.100 (.090-.130)	.170 (.130-.190)	1041
	03-04	*	< LOD	.055 (<LOD-.063)	.101 (.077-.117)	.135 (.111-.180)	888

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum *trans*-Nonachlor (lipid adjusted)

Metabolite of Chlordane

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**18.3** (16.7-20.0)	**17.9** (16.1-20.1)	**31.9** (28.9-36.0)	**55.1** (48.4-62.6)	**79.4** (67.6-88.1)	1933
	01-02	**17.0** (15.2-18.9)	**17.9** (15.5-20.5)	**33.7** (30.2-37.2)	**56.3** (49.6-66.0)	**78.2** (64.0-113)	2286
	03-04	**14.7** (13.1-16.5)	**14.8** (13.5-17.0)	**30.2** (26.7-32.5)	**49.0** (42.6-54.7)	**68.3** (58.6-82.3)	1955
Age group							
12-19 years	99-00	*	< LOD	< LOD	**18.8** (<LOD-20.6)	**25.2** (19.1-28.4)	664
	01-02	*	< LOD	< LOD	**13.4** (11.8-16.4)	**19.2** (15.2-23.5)	758
	03-04	*	< LOD	**8.70** (<LOD-12.5)	**16.1** (10.7-23.7)	**22.6** (16.1-34.6)	589
20 years and older	99-00	**20.8** (19.0-22.8)	**20.7** (18.0-23.5)	**35.4** (30.9-40.3)	**59.9** (51.8-67.6)	**82.7** (74.9-89.6)	1269
	01-02	**19.8** (17.6-22.3)	**20.9** (19.0-23.1)	**36.6** (32.8-41.1)	**60.6** (52.5-69.9)	**84.9** (66.0-123)	1528
	03-04	**16.9** (15.1-18.9)	**17.3** (14.6-20.0)	**31.8** (28.9-35.3)	**51.4** (45.9-58.6)	**74.7** (59.8-90.0)	1366
Gender							
Males	99-00	**17.7** (16.5-19.1)	**17.2** (14.9-20.1)	**30.2** (27.7-34.2)	**51.1** (47.3-58.6)	**78.2** (60.2-88.1)	922
	01-02	**17.0** (14.8-19.5)	**18.3** (14.8-21.1)	**34.4** (28.3-39.3)	**54.8** (45.0-68.9)	**78.2** (59.7-113)	1062
	03-04	**14.8** (12.7-17.3)	**14.6** (12.2-18.0)	**30.8** (26.7-35.3)	**51.0** (42.0-59.4)	**68.6** (56.0-93.8)	955
Females	99-00	**18.8** (16.7-21.1)	**18.4** (16.1-22.2)	**32.9** (29.0-38.3)	**59.0** (48.4-67.6)	**80.8** (71.5-95.5)	1011
	01-02	**17.0** (15.4-18.7)	**17.6** (15.0-20.3)	**32.8** (30.4-36.7)	**56.9** (51.9-65.5)	**78.1** (65.5-111)	1224
	03-04	**14.5** (13.1-16.1)	**15.0** (13.8-16.3)	**28.2** (25.3-32.8)	**48.1** (41.4-52.7)	**68.3** (56.8-79.9)	1000
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**25.1** (22.7-29.5)	**40.7** (35.1-51.8)	**56.3** (45.8-77.2)	650
	01-02	**11.9** (<LOD-14.6)	**10.6** (<LOD-14.5)	**26.0** (19.3-30.4)	**47.9** (36.3-57.2)	**59.8** (49.3-74.1)	558
	03-04	**10.2** (7.86-13.2)	**9.10** (<LOD-11.1)	**20.7** (11.1-34.7)	**39.5** (25.9-65.5)	**62.2** (36.0-93.4)	457
Non-Hispanic blacks	99-00	**20.3** (17.0-24.1)	**17.5** (15.4-23.5)	**35.7** (28.9-45.5)	**77.0** (60.8-90.7)	**107** (84.0-143)	404
	01-02	**18.8** (15.4-22.9)	**19.2** (14.7-22.0)	**36.8** (28.3-50.5)	**73.6** (50.8-110)	**112** (68.7-160)	514
	03-04	**14.4** (12.2-17.0)	**13.8** (11.2-16.3)	**30.8** (26.5-36.1)	**59.9** (47.7-77.7)	**86.6** (56.8-129)	486
Non-Hispanic whites	99-00	**19.1** (17.2-21.1)	**19.0** (16.9-22.2)	**32.8** (28.0-37.6)	**52.5** (44.9-64.4)	**74.0** (62.3-86.7)	722
	01-02	**17.5** (15.6-19.7)	**19.0** (16.3-21.1)	**34.0** (29.7-38.1)	**55.5** (45.9-69.4)	**78.7** (59.1-126)	1052
	03-04	**15.8** (13.7-18.2)	**16.0** (13.8-19.3)	**30.8** (26.4-35.0)	**48.8** (42.1-55.7)	**67.6** (57.5-87.3)	889

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 14.5, 10.5, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum *trans*-Nonachlor (whole weight)

Metabolite of Chlordane

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.109** (.099-.119)	**.110** (.090-.120)	**.210** (.190-.240)	**.370** (.330-.420)	**.550** (.470-.630)	1933
	01-02	**.104** (.093-.116)	**.110** (.100-.120)	**.220** (.190-.250)	**.390** (.330-.480)	**.590** (.430-.800)	2286
	03-04	**.089** (.080-.100)	**.094** (.084-.108)	**.191** (.171-.211)	**.324** (.290-.371)	**.470** (.410-.558)	1955
Age group							
12-19 years	99-00	*	< LOD	< LOD	**.090** (<LOD-.110)	**.120** (.100-.130)	664
	01-02	*	< LOD	< LOD	**.070** (.060-.080)	**.090** (.080-.130)	758
	03-04	*	< LOD	**.041** (<LOD-.060)	**.081** (.054-.117)	**.109** (.081-.161)	589
20 years and older	99-00	**.128** (.116-.141)	**.130** (.110-.150)	**.230** (.210-.260)	**.400** (.360-.460)	**.580** (.490-.690)	1269
	01-02	**.125** (.111-.141)	**.130** (.120-.150)	**.240** (.210-.280)	**.420** (.350-.540)	**.640** (.470-.840)	1528
	03-04	**.106** (.095-.119)	**.112** (.096-.127)	**.210** (.186-.237)	**.355** (.301-.405)	**.520** (.430-.594)	1366
Gender							
Males	99-00	**.106** (.098-.114)	**.100** (.090-.120)	**.210** (.180-.220)	**.350** (.310-.400)	**.520** (.400-.630)	922
	01-02	**.105** (.091-.122)	**.110** (.090-.130)	**.220** (.190-.260)	**.380** (.310-.500)	**.580** (.390-.830)	1062
	03-04	**.092** (.079-.108)	**.098** (.085-.126)	**.202** (.177-.232)	**.343** (.285-.395)	**.458** (.395-.594)	955
Females	99-00	**.111** (.099-.125)	**.110** (.090-.130)	**.220** (.190-.250)	**.390** (.310-.460)	**.580** (.460-.690)	1011
	01-02	**.103** (.093-.113)	**.110** (.090-.120)	**.220** (.180-.240)	**.400** (.340-.450)	**.590** (.430-.830)	1224
	03-04	**.087** (.078-.097)	**.092** (.079-.098)	**.183** (.161-.210)	**.317** (.286-.367)	**.470** (.409-.565)	1000
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**.170** (.120-.210)	**.310** (.240-.340)	**.390** (.320-.520)	650
	01-02	**.071** (<LOD-.091)	**.060** (<LOD-.090)	**.160** (.120-.210)	**.330** (.270-.390)	**.470** (.360-.590)	558
	03-04	**.062** (.047-.082)	**.055** (<LOD-.069)	**.135** (.069-.237)	**.288** (.158-.559)	**.414** (.279-.651)	457
Non-Hispanic blacks	99-00	**.112** (.093-.134)	**.100** (.080-.130)	**.220** (.180-.300)	**.490** (.340-.600)	**.760** (.510-.960)	404
	01-02	**.106** (.085-.131)	**.110** (.080-.130)	**.220** (.160-.310)	**.490** (.320-.680)	**.680** (.410-1.20)	514
	03-04	**.080** (.068-.096)	**.078** (.061-.093)	**.186** (.145-.242)	**.417** (.272-.565)	**.573** (.497-.684)	486
Non-Hispanic whites	99-00	**.116** (.104-.129)	**.120** (.100-.140)	**.220** (.190-.240)	**.370** (.300-.440)	**.510** (.440-.630)	722
	01-02	**.108** (.096-.122)	**.120** (.100-.130)	**.220** (.190-.250)	**.390** (.310-.490)	**.600** (.400-.930)	1052
	03-04	**.098** (.085-.113)	**.103** (.090-.124)	**.205** (.173-.234)	**.327** (.288-.390)	**.461** (.397-.576)	889

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Dichlorodiphenyltrichloroethane (DDT)

CAS No. 50-29-3

General Information

Dichlorodiphenyltrichloroethane (DDT) has been used widely as a broad spectrum insecticide in agriculture and for control of vector-borne diseases. It was produced and used in the U.S. after World War II until 1972, when virtually all use of it was banned. It is still used in some countries, particularly for endemic vector and malaria control. DDT was used at one time as a treatment for head and body lice. DDT usually refers to the technical product, which is a mixture containing *p,p'*-DDT (65%-80%), *o,p'*-DDT (15%-21%), *p,p'*-DDD (4% or less), and trace amounts of several related compounds. DDT is converted in the environment to other more stable chemical forms, including 1,1'-(2,2-dichloroethenylidene)-*bis*[4-chlorobenzene] (DDE) and 1,1'-dichloro-(2,2-*bis*(*p*-chlorophenyl) ethane (DDD). These chemicals are highly persistent in soil, sediments, air, and water, as well as in plant and animal tissues. The biodegradation half-life of DDT in soil varies from 2 to 15 years, depending on conditions.

In the general U.S. population, food, particularly meat, fish, and dairy products, continues to be the primary source of DDT exposure, although DDT and DDE intakes have decreased over time (FDA, 2008; Gunderson, 1988). Food imported from countries that still use DDT may contain the chemical or its residues. DDT can be absorbed after ingestion, inhalation, or dermal exposure. In the body, DDT is converted to DDE and several other metabolites. DDT and DDE are distributed to all body tissues with the highest concentrations found in adipose tissues (ATSDR, 2002; Smith, 1991). Only a small proportion of DDT is metabolized and excreted (Smith, 1991). DDT and DDE can cross the placenta, resulting in fetal exposure. Both

Serum *p,p'*-Dichlorodiphenyltrichloroethane (DDT) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**28.0** (21.9-34.0)	1679
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**26.6** (22.5-36.0)	2305
	03-04	*	**< LOD**	**< LOD**	**11.9** (10.0-15.1)	**19.5** (15.1-27.5)	1965
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	677
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	756
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**9.10** (<LOD-12.2)	595
20 years and older	99-00	*	**< LOD**	**< LOD**	**< LOD**	**30.5** (23.0-37.3)	1002
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**28.1** (23.8-39.0)	1549
	03-04	*	**< LOD**	**< LOD**	**12.9** (10.3-16.5)	**20.7** (15.9-28.7)	1370
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**< LOD**	**25.1** (<LOD-39.3)	799
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**21.6** (<LOD-25.8)	1073
	03-04	*	**< LOD**	**< LOD**	**10.6** (9.10-13.7)	**15.2** (11.8-26.9)	959
Females	99-00	*	**< LOD**	**< LOD**	**< LOD**	**29.4** (23.0-35.8)	880
	01-02	*	**< LOD**	**< LOD**	**18.3** (<LOD-21.9)	**36.6** (25.5-54.3)	1232
	03-04	*	**< LOD**	**< LOD**	**14.0** (10.8-17.5)	**21.0** (18.0-27.8)	1006
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**61.3** (27.0-155)	**155** (59.3-590)	635
	01-02	*	**< LOD**	**< LOD**	**83.1** (33.3-236)	**293** (104-541)	566
	03-04	*	**< LOD**	**8.90** (<LOD-12.9)	**24.0** (18.6-33.3)	**48.6** (31.1-71.1)	461
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**22.3** (<LOD-31.5)	**31.5** (23.2-65.0)	356
	01-02	*	**< LOD**	**< LOD**	**23.2** (<LOD-40.9)	**40.9** (21.2-95.8)	514
	03-04	*	**< LOD**	**9.00** (<LOD-10.4)	**17.5** (14.8-23.2)	**30.7** (19.0-53.4)	490
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	564
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**17.9** (<LOD-20.7)	1061
	03-04	*	**< LOD**	**< LOD**	**9.70** (8.50-11.2)	**12.9** (10.7-16.6)	890

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 20.7, 17.4, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

chemicals are excreted in breast milk, resulting in exposure to nursing infants (Rogan, 1996).

Human health effects from DDT at low environmental doses or at biomonitored levels from low environmental exposures are unknown. In high dose, accidental exposures, overt signs of acute human toxicity include vomiting, tremor, and seizures. Experimental human dosing studies conducted over an 18 month period and during which doses well above environmental levels were given did not demonstrate overt clinical abnormalities (ATSDR, 2002; Hayes et al., 1956). In laboratory animals, both DDT and DDE may induce specific cytochrome P450 isozymes (Nims et al., 1998). DDT may bind to estrogen receptors (Chen et al., 1997); and *o,p'*-DDD and *p,p'*-DDE can produce anti-androgenic effects (Gray et al., 2001). Animal studies reported reduced fertility, premature delivery, reproductive organ abnormalities, and altered behavior after neonatal exposure (Eriksson and Talts, 2000; Gray et al., 2001). Reproductive effects in humans affecting birth weight, fertility, and duration of lactation, have not been consistently demonstrated (Beard, 2006; Gladen and Rogan, 1995; Jusko et al., 2006), although the risk for preterm delivery may be related to maternal DDE levels (Longnecker et al., 2001). Epidemiologic studies of children with environmental exposure to DDT and DDE have not demonstrated neurologic or developmental abnormalities (Gladen et al., 2004; Jusko et al., 2006; Longnecker et al., 2002; Mariussen and Fonnum, 2006). Several reviews of cancer epidemiologic studies have concluded that a link between DDT and breast cancer is inconclusive (Beard, 2006; Calle et al., 2002; Snedeker, 2001). Studies of DDT exposure and pancreatic cancer, lung cancer, and leukemia have also been inconclusive (ADSDR. 2002; Beard, 2006). It is difficult to attribute outcomes in human studies solely to DDT because of potential co-exposure to other persistent organohalogen chemicals (e.g., polychlorinated biphenyls, other organochlorines, dioxins and furans).

A workplace standard for DDT has been established by

Serum *p,p'*-Dichlorodiphenyltrichloroethane (DDT) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	**.170** (.130-.220)	1679
	01-02	*	< LOD	< LOD	< LOD	**.180** (.160-.220)	2305
	03-04	*	< LOD	< LOD	**.078** (.065-.097)	**.128** (.098-.167)	1965
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	677
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	< LOD	< LOD	**.048** (<LOD-.069)	595
20 years and older	99-00	*	< LOD	< LOD	< LOD	**.190** (.150-.230)	1002
	01-02	*	< LOD	< LOD	< LOD	**.200** (.170-.260)	1549
	03-04	*	< LOD	< LOD	**.084** (.068-.106)	**.142** (.105-.189)	1370
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**.150** (<LOD-.240)	799
	01-02	*	< LOD	< LOD	< LOD	**.150** (<LOD-.180)	1073
	03-04	*	< LOD	< LOD	**.071** (.059-.095)	**.108** (.078-.180)	959
Females	99-00	*	< LOD	< LOD	< LOD	**.190** (.150-.230)	880
	01-02	*	< LOD	< LOD	**.130** (<LOD-.150)	**.240** (.180-.400)	1232
	03-04	*	< LOD	< LOD	**.087** (.071-.106)	**.146** (.106-.207)	1006
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**.400** (.190-1.00)	**1.00** (.330-4.26)	635
	01-02	*	< LOD	< LOD	**.530** (.250-1.34)	**1.62** (.570-4.01)	566
	03-04	*	< LOD	**.063** (<LOD-.079)	**.146** (.114-.203)	**.313** (.189-.627)	461
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**.120** (<LOD-.170)	**.180** (.140-.420)	356
	01-02	*	< LOD	< LOD	**.130** (<LOD-.290)	**.250** (.120-.530)	514
	03-04	*	< LOD	**.051** (<LOD-.061)	**.112** (.080-.143)	**.201** (.132-.343)	490
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	564
	01-02	*	< LOD	< LOD	< LOD	**.130** (<LOD-.140)	1061
	03-04	*	< LOD	< LOD	**.064** (.054-.075)	**.086** (.074-.107)	890

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

OSHA and a guidance established by ACGIH. IARC classifies DDT (*p,p'*-DDT) as a possible human carcinogen. NTP considers DDT as being reasonably anticipated to be a human carcinogen. More information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA at: http://www.epa.gov/pestcides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

DDE persists in the body longer than DDT, so serum DDE levels may be an indicator of historic exposure and may be higher than DDT levels in the same person. In general, levels of DDT and DDE increase as a person ages as a result of cumulative exposure (ATSDR, 2002; Smith, 1991). Since the 1970's, mean serum levels of DDT and DDE in the U.S. population declined by about fivefold to tenfold, compared to levels observed in this *Report* (Anderson et al., 1998; Stehr-Green, 1989). Declining DDE levels over time have also been observed in the German population, and the most recent median levels for German adults and children are similar to levels in this *Report* (Becker et al., 2002; Heudorf et al., 2003; Link et al., 2005). Median DDE levels among a population-based sample of Swedish women in 1996-1997 were similar to females in the NHANES 1999-2000 subsample (Glynn et al., 2003). A study of New Zealand adults sampled in 1996-1997 reported median DDE levels that were about threefold higher than the median for adults in the NHANES 1999-2000 subsample (Bates et al., 2004). In a population-based sample of men and women from eastern Slovakia, the lipid-adjusted geometric mean levels of DDT and DDE were each fivefold to tenfold higher than the 95th percentile and geometric mean levels, respectively, for males and females in the NHANES 1999-2000 subsample (Pavuk et al., 2004).

Compared to females in the NHANES 1999-2000 subsample, mean DDE levels were about fivefold higher among women of southern Spain exposed by virtue of

Serum *p,p'*-Dichlorodiphenyldichloroethene (DDE) (lipid adjusted)

Metabolite of Dichlorodiphenyltrichloroethane

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**260** (226-298)	**226** (184-278)	**537** (476-631)	**1150** (976-1350)	**1830** (1410-2300)	1964
	01-02	**295** (267-327)	**251** (228-278)	**598** (521-699)	**1410** (1210-1500)	**2320** (1830-2780)	2298
	03-04	**238** (195-292)	**203** (163-275)	**509** (376-655)	**1170** (836-1570)	**1860** (1400-2380)	1956
Age group							
12-19 years	99-00	**118** (102-135)	**108** (97.7-119)	**185** (141-237)	**339** (243-479)	**528** (339-812)	686
	01-02	**124** (106-146)	**113** (100-140)	**213** (172-253)	**319** (282-389)	**456** (343-722)	758
	03-04	**105** (84.7-129)	**93.6** (81.0-114)	**167** (123-240)	**341** (211-586)	**522** (313-1430)	588
20 years and older	99-00	**297** (256-344)	**269** (213-323)	**608** (530-693)	**1260** (1030-1550)	**2020** (1520-2730)	1278
	01-02	**338** (303-376)	**285** (249-337)	**695** (595-798)	**1480** (1310-1700)	**2550** (1980-3080)	1540
	03-04	**268** (217-332)	**233** (175-314)	**557** (420-734)	**1270** (877-1800)	**1990** (1500-2470)	1368
Gender							
Males	99-00	**249** (220-283)	**223** (182-262)	**494** (380-578)	**1010** (789-1130)	**1430** (1080-2160)	937
	01-02	**285** (252-323)	**248** (222-285)	**520** (441-627)	**1160** (937-1360)	**1900** (1580-2490)	1069
	03-04	**235** (193-288)	**200** (164-262)	**466** (331-653)	**1000** (763-1400)	**1610** (1210-2320)	955
Females	99-00	**270** (226-322)	**234** (184-302)	**601** (492-711)	**1350** (1040-1720)	**2210** (1570-2810)	1027
	01-02	**305** (273-341)	**256** (219-297)	**708** (567-844)	**1480** (1410-1710)	**2670** (1940-3300)	1229
	03-04	**241** (193-301)	**207** (161-281)	**539** (386-735)	**1250** (813-1900)	**2010** (1500-2450)	1001
Race/ethnicity							
Mexican Americans	99-00	**674** (574-792)	**624** (545-701)	**1350** (1090-1660)	**3090** (2040-4950)	**4950** (3070-9350)	657
	01-02	**652** (569-747)	**561** (455-690)	**1400** (1050-1950)	**4110** (2520-6550)	**7080** (3080-15600)	566
	03-04	**444** (362-545)	**373** (283-522)	**875** (608-1170)	**2150** (1520-2470)	**3290** (2380-9240)	457
Non-Hispanic blacks	99-00	**295** (241-362)	**251** (199-313)	**668** (492-874)	**1850** (1040-2220)	**2300** (1560-5680)	416
	01-02	**324** (262-400)	**248** (223-296)	**762** (583-999)	**1620** (1180-2980)	**3260** (1270-6900)	515
	03-04	**262** (233-295)	**216** (173-267)	**589** (453-747)	**1620** (1130-2310)	**2860** (1880-3440)	487
Non-Hispanic whites	99-00	**217** (189-249)	**194** (162-238)	**438** (355-507)	**825** (647-1010)	**1160** (1010-1350)	732
	01-02	**253** (226-284)	**225** (203-254)	**463** (402-558)	**1150** (878-1340)	**1640** (1410-1940)	1053
	03-04	**208** (165-263)	**177** (148-238)	**417** (302-564)	**907** (574-1480)	**1490** (909-2300)	888

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 18.6, 8.3, and 7.8, respectively.

nearby agriculture (Botella et al., 2004). A small study of Indian men with background exposure reported mean serum DDT and DDE levels that were around fiftyfold higher than the 95th percentile for DDT and tenfold to twentyfold higher than the geometric mean DDE levels among males in this *Report* (Bhatnagar et al., 2004). Consumers of Great Lakes sport fish had mean serum DDE levels that were only slightly higher than nonconsumers, 309 versus 268 ng/g lipid, which is similar to the overall geometric mean of 260 ng/g lipid in the NHANES 1999-2000 subsample (Bloom et al., 2005). High mean levels of whole blood DDT (about 3,860 ng/L) and DDE (about 14,490 ng/L) were found many years ago in a study of pesticide workers in Argentina (Radomski et al., 1971). Workers involved in production or application of DDT developed neurologic abnormalities associated with blood levels around 100-300 µg/L, considerably higher than levels in this *Report* (Smith, 1991).

In the NHANES 1999-2000, 2001-2002 and 2003-2004 subsamples, serum levels of *o,p'*-DDT were below the limits of detection. In a subsample of NHANES II (1976-1980) participants, less than one percent had detectable serum levels of *o,p'*-DDT (Stehr-Green, 1989).

Finding a measurable amount of *p,p'*-DDT, *o,p'*-DDT, or *p,p'*-DDE in serum does not mean that the level of the chemical causes an adverse health effect. Biomonitoring studies on levels of DDT and DDE provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DDT or DDE than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum *p,p'*-Dichlorodiphenyldichloroethene (DDE) (whole weight)

Metabolite of Dichlorodiphenyltrichloroethane

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.54** (1.33-1.79)	**1.31** (1.09-1.66)	**3.50** (2.97-4.27)	**7.49** (6.14-9.25)	**11.6** (9.25-14.8)	1964
	01-02	**1.81** (1.64-2.01)	**1.57** (1.37-1.72)	**3.97** (3.43-4.59)	**8.81** (7.85-10.1)	**15.4** (12.9-17.6)	2298
	03-04	**1.45** (1.18-1.79)	**1.26** (1.00-1.58)	**3.16** (2.40-4.21)	**7.07** (5.55-9.80)	**12.1** (8.37-16.0)	1956
Age group							
12-19 years	99-00	**.561** (.488-.646)	**.520** (.430-.600)	**.870** (.680-1.18)	**1.52** (1.13-2.25)	**2.32** (1.76-3.56)	686
	01-02	**.623** (.534-.726)	**.590** (.500-.730)	**1.00** (.820-1.22)	**1.65** (1.39-2.07)	**2.30** (1.91-3.14)	758
	03-04	**.516** (.419-.635)	**.456** (.385-.557)	**.796** (.611-1.19)	**1.69** (.994-2.69)	**2.51** (1.56-6.71)	588
20 years and older	99-00	**1.83** (1.56-2.14)	**1.61** (1.26-2.07)	**4.17** (3.48-4.66)	**8.12** (6.37-10.6)	**12.3** (9.87-16.7)	1278
	01-02	**2.14** (1.91-2.39)	**1.77** (1.61-2.05)	**4.59** (4.10-5.26)	**9.75** (8.34-11.5)	**16.8** (13.7-19.1)	1540
	03-04	**1.69** (1.36-2.10)	**1.46** (1.12-1.96)	**3.68** (2.66-4.96)	**7.91** (6.01-11.0)	**12.8** (9.25-16.8)	1368
Gender							
Males	99-00	**1.49** (1.30-1.70)	**1.25** (1.10-1.44)	**3.02** (2.57-3.80)	**6.43** (5.40-8.00)	**9.63** (6.63-15.6)	937
	01-02	**1.77** (1.57-2.01)	**1.59** (1.36-1.76)	**3.40** (3.03-4.10)	**7.48** (6.43-8.75)	**13.1** (9.66-17.6)	1069
	03-04	**1.46** (1.18-1.80)	**1.30** (1.04-1.58)	**2.80** (2.18-4.13)	**6.71** (5.51-8.54)	**9.93** (7.51-15.4)	955
Females	99-00	**1.59** (1.32-1.92)	**1.38** (1.03-1.99)	**4.05** (3.15-4.79)	**8.18** (6.36-11.5)	**13.2** (9.81-18.5)	1027
	01-02	**1.85** (1.66-2.06)	**1.49** (1.32-1.75)	**4.57** (3.81-5.47)	**10.2** (9.01-11.9)	**16.8** (13.4-19.7)	1229
	03-04	**1.45** (1.16-1.82)	**1.25** (.965-1.66)	**3.55** (2.43-4.59)	**7.87** (5.41-12.6)	**13.7** (8.50-17.3)	1001
Race/ethnicity							
Mexican Americans	99-00	**3.92** (3.40-4.51)	**3.52** (3.17-3.91)	**8.22** (7.26-10.4)	**22.0** (12.2-32.2)	**32.2** (19.7-48.1)	657
	01-02	**3.92** (3.37-4.57)	**3.53** (2.68-4.34)	**9.34** (7.31-12.5)	**26.6** (17.9-38.3)	**40.9** (26.8-90.5)	566
	03-04	**2.69** (2.18-3.32)	**2.24** (1.70-3.24)	**5.78** (4.54-7.21)	**13.0** (9.53-15.6)	**22.9** (15.3-43.4)	457
Non-Hispanic blacks	99-00	**1.63** (1.31-2.02)	**1.37** (1.11-1.66)	**3.84** (3.01-5.69)	**11.2** (6.57-13.3)	**14.6** (8.88-35.2)	416
	01-02	**1.82** (1.46-2.28)	**1.38** (1.22-1.72)	**4.39** (3.52-6.06)	**10.6** (7.24-17.6)	**19.4** (8.51-49.3)	515
	03-04	**1.47** (1.30-1.65)	**1.20** (.963-1.51)	**3.76** (2.85-4.75)	**9.23** (7.19-14.9)	**16.8** (14.7-20.6)	487
Non-Hispanic whites	99-00	**1.32** (1.14-1.53)	**1.13** (1.01-1.35)	**2.88** (2.34-3.36)	**5.75** (4.62-6.53)	**8.04** (6.32-9.81)	732
	01-02	**1.57** (1.39-1.76)	**1.41** (1.27-1.58)	**3.11** (2.56-3.68)	**7.00** (6.02-8.34)	**11.3** (8.60-13.7)	1053
	03-04	**1.29** (1.01-1.64)	**1.12** (.890-1.49)	**2.63** (1.84-3.90)	**6.36** (3.90-8.71)	**9.71** (6.01-15.0)	888

Serum *o,p'*-Dichlorodiphenyltrichloroethane (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1669
	01-02	*	< LOD	< LOD	< LOD	< LOD	2279
	03-04	*	< LOD	< LOD	< LOD	< LOD	1946
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	< LOD	< LOD	< LOD	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1002
	01-02	*	< LOD	< LOD	< LOD	< LOD	1523
	03-04	*	< LOD	< LOD	< LOD	< LOD	1358
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	796
	01-02	*	< LOD	< LOD	< LOD	< LOD	1059
	03-04	*	< LOD	< LOD	< LOD	< LOD	949
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	873
	01-02	*	< LOD	< LOD	< LOD	< LOD	1220
	03-04	*	< LOD	< LOD	< LOD	< LOD	997
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	632
	01-02	*	< LOD	< LOD	< LOD	< LOD	565
	03-04	*	< LOD	< LOD	< LOD	< LOD	458
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	354
	01-02	*	< LOD	< LOD	< LOD	< LOD	507
	03-04	*	< LOD	< LOD	< LOD	< LOD	486
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	560
	01-02	*	< LOD	< LOD	< LOD	< LOD	1045
	03-04	*	< LOD	< LOD	< LOD	< LOD	880

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 20.7, 17.4, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum *o,p'*-Dichlorodiphenyltrichloroethane (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1669
	01-02	*	< LOD	< LOD	< LOD	< LOD	2279
	03-04	*	< LOD	< LOD	< LOD	< LOD	1946
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	< LOD	< LOD	< LOD	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1002
	01-02	*	< LOD	< LOD	< LOD	< LOD	1523
	03-04	*	< LOD	< LOD	< LOD	< LOD	1358
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	796
	01-02	*	< LOD	< LOD	< LOD	< LOD	1059
	03-04	*	< LOD	< LOD	< LOD	< LOD	949
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	873
	01-02	*	< LOD	< LOD	< LOD	< LOD	1220
	03-04	*	< LOD	< LOD	< LOD	< LOD	997
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	632
	01-02	*	< LOD	< LOD	< LOD	< LOD	565
	03-04	*	< LOD	< LOD	< LOD	< LOD	458
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	354
	01-02	*	< LOD	< LOD	< LOD	< LOD	507
	03-04	*	< LOD	< LOD	< LOD	< LOD	486
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	560
	01-02	*	< LOD	< LOD	< LOD	< LOD	1045
	03-04	*	< LOD	< LOD	< LOD	< LOD	880

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Endrin

CAS No. 72-20-8

General Information

Endrin, a stereoisomer of dieldrin, is no longer manufactured in the U.S. All uses of the pesticide in the U.S. have been cancelled by the U.S. EPA. Endrin was used as an insecticide, rodenticide and avicide. Endrin was not widely used as a termiticide, unlike aldrin and dieldrin. Depending on soil conditions, endrin can persist for years. Ketoendrin is a major photodegradation product (IPCS, 1992). Endrin has been detected in soils, and occasionally at low levels in sediment and surface waters, largely the result of historical agricultural application or run off from contaminated soils (ATSDR, 1996; IPCS, 1992).

General population exposure can occur after ingestion of endrin residues on food items imported from countries where endrin is still used, or from contact with contaminated soils and sediments in areas where endrin was applied, manufactured, or discarded. Over time, endrin has been detected with declining frequency in U.S. total diet surveys (FDA, 2008). Endrin is absorbed rapidly after ingestion, inhalation or dermal exposure routes. In the body, endrin is converted rapidly to its major metabolite, *anti*-12-hydroxyendrin. Further conversion occurs to 12-ketoendrin and various conjugated metabolites which are excreted in urine and feces. Because it is metabolized so rapidly, endrin usually is not detected in serum of exposed individuals, unless the dose is high and the exposure is very recent. Endrin does not accumulate in body tissues (IPCS, 1992; Smith, 1991).

Human health effects from endrin at low environmental doses or at biomonitored levels from low environmental exposures are unknown. At high doses, endrin blocks inhibitory neurotransmitters in the central nervous system resulting in excitation and seizures (Narahashi et al., 1992). An epidemic of acute endrin poisoning, characterized by generalized seizures in previously healthy persons occurred in Pakistan when sugar contaminated with endrin was ingested (Rowley et al., 1987). High doses produced renal tubular necrosis and diffuse kidney degeneration in animals. Hepatic effects of endrin exposure have included necrosis, fatty infiltration, and inflammation (Smith, 1991). Skeletal abnormalities and cleft palate in the offspring were associated with endrin when it was fed to pregnant laboratory rodents (Chernoff et al., 1979; Kavlock et al., 1981).

Serum Endrin (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	**5.10** (<LOD-5.40)	2187
	03-04	*	< LOD	< LOD	< LOD	< LOD	1825
Age group							
12-19 years	01-02	*	< LOD	< LOD	**5.20** (<LOD-5.50)	**5.60** (5.40-5.70)	730
	03-04	*	< LOD	< LOD	< LOD	< LOD	539
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1457
	03-04	*	< LOD	< LOD	< LOD	< LOD	1286
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	**5.20** (<LOD-5.40)	1022
	03-04	*	< LOD	< LOD	< LOD	< LOD	885
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1165
	03-04	*	< LOD	< LOD	< LOD	< LOD	940
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**5.30** (<LOD-6.50)	547
	03-04	*	< LOD	< LOD	< LOD	< LOD	433
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	**5.40** (<LOD-6.30)	487
	03-04	*	< LOD	< LOD	< LOD	< LOD	446
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	**5.10** (<LOD-5.40)	1000
	03-04	*	< LOD	< LOD	< LOD	< LOD	831

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 5.09 and 7.8.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

The U.S. EPA has established environmental standards for endrin, and the FDA monitors foods for pesticide residues. Workplace exposure standards for endrin have been established by OSHA. IARC has determined that endrin is not classifiable with regard to human carcinogenicity. Information about external exposure (i.e., environmental levels) and health effects of endrin is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

In the NHANES 2001-2002 and 2003-2004 subsamples, serum levels of endrin were below the limit of detection. This finding is consistent with other general population studies (Bates et al., 2004; Ward et al., 2000). In a small study of Spanish women hospitalized for elective surgery, endrin was detected in 9% of serum samples, with the highest value 6.24 ng/mL (about 6.24 ng/g of serum) (Botella et al., 2004).

Finding a measurable amount of endrin in serum does not mean that the level of endrin causes an adverse health effect. Biomonitoring studies on levels of endrin provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of endrin than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum Endrin (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	.020 (<LOD-.020)	2187
	03-04	*	< LOD	< LOD	< LOD	< LOD	1825
Age group							
12-19 years	01-02	*	< LOD	< LOD	.020 (<LOD-.020)	.020 (.020-.020)	730
	03-04	*	< LOD	< LOD	< LOD	< LOD	539
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1457
	03-04	*	< LOD	< LOD	< LOD	< LOD	1286
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	.020 (<LOD-.020)	1022
	03-04	*	< LOD	< LOD	< LOD	< LOD	885
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1165
	03-04	*	< LOD	< LOD	< LOD	< LOD	940
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	.020 (<LOD-.020)	547
	03-04	*	< LOD	< LOD	< LOD	< LOD	433
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	.020 (<LOD-.020)	487
	03-04	*	< LOD	< LOD	< LOD	< LOD	446
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	.020 (<LOD-.020)	1000
	03-04	*	< LOD	< LOD	< LOD	< LOD	831

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Hexachlorobenzene

CAS No. 118-74-1

General Information

Hexachlorobenzene (HCB) was used from the 1930's to the 1970's in the U.S. primarily as a fungicide and seed treatment until the U.S. EPA cancelled its use in 1984. Although it is not manufactured as an end-product in the U.S., HCB may be created as either a byproduct or an impurity in the manufacturing process for certain chemicals and pesticides.

Hexachlorobenzene has entered the environment as a result of industrial activities and pesticide applications, and has been detected in soil, air, water, and sediment (Barber et al., 2005). It is a persistent chemical and bioaccumulates in both aquatic and terrestrial food chains (ATSDR, 2002). The general population may be exposed to HCB through diet, particularly by consuming fish, wildfowl, or game taken from areas with HCB contamination, and foods with a high fat content. The FDA dietary surveys have shown that over time, HCB has been detected in fewer foods since the 1980s (FDA, 2008; Gunderson, 1988). Workers in chemical manufacturing industries may be exposed to HCB via inhalation or dermal pathways.

HCB is well absorbed after oral administration, distributes widely throughout the body, and accumulates in fatty tissues where it persists for years. HCB is slowly metabolized, and elimination occurs by renal and fecal routes; breast milk is an additional route of elimination in nursing women. Urinary metabolites include pentachlorophenol (PCP), 2,4,5-trichlorophenol (2,4,5-TCP) and 2,4,6-trichlorophenol (2,4,6-TCP) (To-Figueras et al., 1997); these metabolites can also be produced after exposure to other chlorinated compounds (Kohli et al., 1976). Therefore, measuring HCB in serum is a specific indicator of exposure to the parent

Serum Hexachlorobenzene (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1702
	01-02	*	< LOD	< LOD	< LOD	< LOD	2277
	03-04	**15.2** (14.5-15.9)	**14.9** (14.2-15.7)	**19.0** (18.1-20.3)	**24.4** (22.6-26.4)	**28.9** (25.6-32.8)	1961
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	591
	01-02	*	< LOD	< LOD	< LOD	< LOD	747
	03-04	**13.3** (12.5-14.1)	**13.4** (11.5-14.9)	**16.7** (15.5-18.4)	**20.7** (19.7-22.7)	**25.3** (22.7-30.2)	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1111
	01-02	*	< LOD	< LOD	< LOD	< LOD	1530
	03-04	**15.5** (14.7-16.2)	**15.1** (14.5-15.9)	**19.4** (18.3-20.9)	**24.8** (22.7-26.6)	**29.0** (25.6-33.6)	1373
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	807
	01-02	*	< LOD	< LOD	< LOD	< LOD	1058
	03-04	**14.5** (13.8-15.3)	**14.2** (13.4-15.0)	**18.1** (17.0-19.3)	**23.6** (21.0-25.6)	**26.9** (25.2-31.3)	957
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	895
	01-02	*	< LOD	< LOD	< LOD	< LOD	1219
	03-04	**15.8** (15.0-16.6)	**15.7** (15.1-16.4)	**20.0** (18.7-21.4)	**24.9** (23.0-28.6)	**29.8** (26.5-33.7)	1004
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	583
	01-02	*	< LOD	< LOD	< LOD	< LOD	554
	03-04	**16.2** (14.9-17.7)	**15.3** (14.7-16.4)	**20.4** (18.3-22.5)	**27.6** (24.7-29.4)	**33.7** (27.6-44.6)	460
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	350
	01-02	*	< LOD	< LOD	< LOD	< LOD	511
	03-04	**14.5** (13.9-15.0)	**14.1** (13.7-15.1)	**18.3** (16.6-19.9)	**22.3** (20.9-24.0)	**26.6** (23.9-30.9)	488
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	< LOD	< LOD	< LOD	1052
	03-04	**15.1** (14.4-16.0)	**15.0** (14.2-15.9)	**19.2** (17.9-20.8)	**24.3** (22.3-26.4)	**28.2** (24.9-32.8)	888

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 118.0, 31.4, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

chemical.

Human health effects from HCB at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Chronic feeding studies in animals have demonstrated kidney injury, immunologic abnormalities, reproductive and developmental toxicities, and liver and thyroid cancers (ATSDR, 2002). In humans, very high, acute doses produce central nervous system depression and seizures. HCB interferes with normal heme synthesis, which is manifested by increased delta-aminolevulinic acid synthase activity and decreased uroporphyrinogen decarboxylase activity. With chronic exposure, a consequence of these heme abnormalities is a condition known as acquired porphyria cutanea tarda. This condition, as well as hypertrichosis, arthritis, thyromegaly, anorexia, and weakness, were seen in an epidemic of poisoning in Turkey that occurred from 1955 to 1959 when HCB-treated seed grain was diverted for bread production. Infants were exposed transplacentally and through breast milk, and many died before 2 years of age (Peters et al., 1982; Schmid, 1960).

IARC classifies hexachlorobenzene as possibly carcinogenic to humans, and NTP classifies hexachlorobenzene as reasonably anticipated to be a human carcinogen. ACGIH has developed workplace exposure limits for HCB. The U.S. EPA has established a drinking water standard, and the FDA has established a bottled water standard for HCB. More information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA at: http://www.epa.gov/pesticides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Serum concentrations reflect the body burden of HCB. HCB levels were generally below the limits of detection

Serum Hexachlorobenzene (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1702
	01-02	*	< LOD	< LOD	< LOD	< LOD	2277
	03-04	**.092** (.088-.097)	**.090** (.086-.095)	**.120** (.113-.126)	**.157** (.145-.167)	**.186** (.169-.212)	1961
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	591
	01-02	*	< LOD	< LOD	< LOD	< LOD	747
	03-04	**.065** (.062-.069)	**.064** (.060-.069)	**.079** (.072-.086)	**.102** (.091-.111)	**.123** (.111-.141)	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1111
	01-02	*	< LOD	< LOD	< LOD	< LOD	1530
	03-04	**.097** (.092-.102)	**.095** (.090-.099)	**.123** (.118-.130)	**.160** (.147-.175)	**.191** (.174-.223)	1373
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	807
	01-02	*	< LOD	< LOD	< LOD	< LOD	1058
	03-04	**.090** (.085-.095)	**.087** (.082-.094)	**.115** (.107-.122)	**.147** (.135-.163)	**.179** (.159-.203)	957
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	895
	01-02	*	< LOD	< LOD	< LOD	< LOD	1219
	03-04	**.095** (.089-.100)	**.092** (.088-.099)	**.123** (.118-.132)	**.163** (.148-.176)	**.190** (.176-.226)	1004
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	583
	01-02	*	< LOD	< LOD	< LOD	< LOD	554
	03-04	**.098** (.089-.109)	**.090** (.081-.107)	**.125** (.114-.152)	**.171** (.157-.203)	**.225** (.178-.258)	460
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	350
	01-02	*	< LOD	< LOD	< LOD	< LOD	511
	03-04	**.081** (.077-.085)	**.078** (.073-.083)	**.104** (.095-.118)	**.140** (.127-.155)	**.167** (.145-.196)	488
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	< LOD	< LOD	< LOD	1052
	03-04	**.094** (.088-.099)	**.092** (.086-.097)	**.121** (.114-.129)	**.156** (.143-.173)	**.182** (.163-.218)	888

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

in the NHANES 1999-2000 and 2001-2002 subsamples. As a result of the lower limit of detection in NHANES 2003-2004, more HCB levels were quantified. Age-related increases of HCB in body fat and serum have been consistently noted in general population studies (Becker et al., 2002; Bertram et al., 1986; Glynn et al., 2003). In a representative sample of the 1998 German adult population, HCB levels were directly related to age, and the geometric mean concentration of HCB in whole blood was 0.44 µg/L, lower than the limit of detection (on a lipid adjusted basis) in NHANES 1999-2000 and 2001-2002, but approximately five times higher than the overall geometric mean level in 2003-2004 (Becker et al., 2002). In the 1976-1980 NHANES subsample, HCB detection in serum also was proportional to age, but overall, only 4.9% of participants had quantifiable levels (Stehr-Green, 1989). In Spain, factory workers chronically exposed to HCB and residents near the factory had serum HCB levels that were 150 to 50 times higher, respectively, than the limits of detection (on a whole weight basis) in NHANES 1999-2000 and 2001-2002 (Herrero et al., 1999). Residency near industrial or agricultural areas has been associated with higher serum HCB levels (Barber et al., 2005; Bradman et al., 2006). Over the past two decades, however, declines in background HCB levels ranging from around 50%-90% have been documented in studies using cord blood (Dallaire et al., 2002; Lackman, 2002) and among children (Link et al., 2005); the more recent values in these studies were similar to the lipid adjusted limit of detection in NHANES 1999-2000 and 2001-2002 (Dallaire et al., 2002; Lackmann, 2002; Link et al., 2005).

Finding a measurable amount of hexachlorobenzene in serum does not mean that the level of the hexachlorobenzene causes an adverse health effect. Biomonitoring studies on levels of HCB provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of hexachlorobenzene than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Hexachlorocyclohexane

CAS No. 608-73-1

beta-Hexachlorocyclohexane

CAS No. 319-85-7

gamma-Hexachlorocyclohexane

CAS No. 58-89-9

General Information

Hexachlorocyclohexane (HCH), formerly referred to as benzene hexachloride, exists in several isomeric forms, including *alpha*, *beta*, *gamma*, and *delta*. The *gamma* isomer, commonly known as lindane, can be used as an insecticide and has been used to kill soil-dwelling and plant-eating insects. The other isomers can be formed during the synthesis of lindane, and have been used either as fungicides or to synthesize other chemicals. Technical grade HCH is a mixture of all four isomers, containing about 64% *alpha* and 10%-15% *gamma* isomers. It is no longer produced or sold in the U.S. In 2006, the U.S. EPA cancelled agricultural uses of lindane (ATSDR, 2005). Lindane (1%) lotion and shampoo are available by prescription for single-use application to treat human scabies and head lice.

HCH isomers, particularly *alpha* and *gamma* have been detected widely in air, soil, water, and sediment as a result of historic production and use. As pesticide applications of HCH were increasingly restricted or eliminated, environmental levels declined. Lindane has a half-life of about two weeks in soils and water. HCH does not bioaccumulate to an appreciable extent in plants (ATSDR, 2005). However, HCH isomers are lipophilic, so they can accumulate in fatty tissues of animals. General population

Serum *beta*-Hexachlorocyclohexane (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**9.68** (<LOD-10.9)	**< LOD**	**19.1** (16.0-21.6)	**42.0** (33.4-50.6)	**68.9** (50.6-89.5)	1893
	01-02**	*	**< LOD**	**16.0** (14.2-17.3)	**36.7** (30.4-45.7)	**67.2** (50.3-85.7)	2291
	03-04	*	**< LOD**	**14.1** (12.1-16.5)	**32.1** (27.1-37.8)	**56.5** (43.7-69.4)	1959
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**11.7** (<LOD-16.1)	653
	01-02**	*	**< LOD**	**< LOD**	**< LOD**	**13.1** (9.70-19.0)	758
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**8.80** (<LOD-14.7)	589
20 years and older	99-00	**10.9** (9.61-12.4)	**< LOD**	**21.1** (18.9-24.0)	**46.0** (35.9-56.8)	**73.4** (52.7-96.0)	1240
	01-02**	**9.87** (9.04-10.8)	**7.80** (6.90-8.90)	**17.4** (16.0-20.5)	**39.6** (33.2-52.0)	**71.7** (53.7-96.2)	1533
	03-04	**7.89** (<LOD-9.09)	**< LOD**	**16.3** (13.6-18.4)	**35.2** (29.6-42.5)	**62.2** (48.2-87.6)	1370
Gender							
Males	99-00	*	**< LOD**	**14.6** (10.8-19.1)	**29.8** (23.3-38.7)	**44.9** (32.8-68.9)	901
	01-02**	*	**< LOD**	**12.9** (11.1-15.7)	**27.5** (24.0-34.4)	**45.7** (35.2-55.6)	1067
	03-04	*	**< LOD**	**10.4** (8.70-12.5)	**21.6** (17.7-26.4)	**35.3** (26.1-49.9)	952
Females	99-00	**11.1** (9.56-12.8)	**< LOD**	**22.0** (19.1-27.6)	**51.3** (42.2-67.6)	**81.8** (64.4-111)	992
	01-02**	**10.2** (9.46-11.0)	**7.70** (6.90-8.50)	**18.5** (16.2-22.7)	**47.5** (37.6-62.0)	**84.7** (62.0-111)	1224
	03-04	**8.43** (<LOD-9.45)	**< LOD**	**18.6** (16.9-21.5)	**41.8** (33.9-51.4)	**70.3** (62.2-98.4)	1007
Race/ethnicity							
Mexican Americans	99-00	**16.7** (13.7-20.2)	**15.5** (11.6-20.4)	**37.7** (29.6-47.3)	**97.9** (62.6-135)	**142** (99.8-199)	632
	01-02**	**13.1** (11.6-14.7)	**11.8** (9.60-13.4)	**25.8** (21.1-32.7)	**69.4** (50.8-87.6)	**134** (85.7-166)	563
	03-04	**10.5** (8.66-12.8)	**10.0** (<LOD-12.7)	**23.8** (17.5-29.9)	**50.1** (30.0-70.3)	**70.3** (42.5-123)	460
Non-Hispanic blacks	99-00	*	**< LOD**	**15.4** (12.0-23.1)	**37.9** (30.2-42.2)	**49.9** (40.9-81.1)	403
	01-02**	*	**< LOD**	**12.0** (8.20-16.2)	**36.2** (18.4-73.4)	**71.2** (31.9-178)	513
	03-04	*	**< LOD**	**9.70** (8.30-11.9)	**27.1** (21.1-36.3)	**48.2** (34.8-54.3)	487
Non-Hispanic whites	99-00	*	**< LOD**	**17.5** (14.2-20.5)	**34.7** (25.2-46.1)	**51.6** (40.0-70.8)	702
	01-02**	*	**< LOD**	**14.4** (11.8-16.8)	**31.9** (26.6-37.8)	**52.0** (37.7-69.5)	1051
	03-04	*	**< LOD**	**12.8** (10.9-14.7)	**27.6** (22.1-32.2)	**40.8** (32.3-56.5)	887

Limits of detection (LOD, see Data Analysis section) for survey years 99-00, 01-02, and 03-04 are 9.36, 6.76, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.
**In survey period 2001-2002, each result has been multiplied by 1.5528. See the section "What's New" at the beginning of this *Report* for details.

exposure to HCH is through the diet. The U.S. FDA pesticide monitoring program has shown a temporal decline in the detection of lindane, from 6% of samples in 1982-1984 to 2% in 1994 (FDA, 2008; Gunderson 1988). Pesticide applicators or agricultural workers could be exposed to HCH by inhalation and dermal pathways.

HCH isomers are absorbed after inhalation, ingestion, or dermal exposure. Distribution is mainly to fatty tissues. After dermal application of lindane 1% lotion, the serum half-life was about 20 hours among children (Ginsburg et al., 1977). The *beta* isomer accumulates in fatty tissues and is metabolized more slowly, resulting in a half-life of about seven years. HCH isomers are metabolized to chlorophenol metabolites that are excreted in the urine (Angerer et al., 1983). HCH crosses the placenta and is also excreted in breast milk (Radomski et al., 1971; Rogan, 1996; Saxena et al., 1981).

Human health effects from HCH isomers at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Acute high dose toxicity in rodents affects the central nervous system producing decreased activity, ataxia, and seizures. When animals were chronically fed lindane at high doses, enlarged livers, hepatic enzyme induction, and nephropathy developed (IPCS, 2002). Acute high doses of lindane after ingestion or excessive skin application of the 1% lotion have produced seizures in humans, probably by blocking inhibitory neurotransmitters in the central nervous system. Workers who directly handled HCH have complained of headache, paresthesias, tremors, and memory loss (Nigam et al., 1986). OSHA and ACGIH have established workplace standards and guidelines, respectively, for lindane. U.S. EPA has established a drinking water standard, and FDA has established a bottled water standard and food residue tolerances for lindane. IARC classifies

Serum *beta*-Hexachlorocyclohexane (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.058** (<LOD-.066)	**< LOD**	**.120** (.100-.150)	**.290** (.220-.360)	**.450** (.360-.560)	1893
	01-02**	*	**< LOD**	**.100** (.090-.120)	**.250** (.210-.310)	**.460** (.340-.600)	2291
	03-04	*	**< LOD**	**.092** (.081-.103)	**.216** (.173-.254)	**.372** (.294-.442)	1959
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**.050** (<LOD-.070)	653
	01-02**	*	**< LOD**	**< LOD**	**< LOD**	**.080** (.050-.100)	758
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.048** (<LOD-.064)	589
20 years and older	99-00	**.067** (.059-.077)	**< LOD**	**.140** (.120-.160)	**.330** (.240-.410)	**.480** (.410-.620)	1240
	01-02**	**.062** (.057-.069)	**.050** (.050-.060)	**.120** (.100-.140)	**.270** (.230-.350)	**.480** (.370-.690)	1533
	03-04	**.050** (<LOD-.058)	**< LOD**	**.103** (.089-.125)	**.234** (.191-.290)	**.412** (.308-.587)	1370
Gender							
Males	99-00	*	**< LOD**	**.090** (.080-.120)	**.210** (.160-.250)	**.290** (.220-.470)	901
	01-02**	*	**< LOD**	**.080** (.070-.100)	**.200** (.150-.260)	**.310** (.250-.400)	1067
	03-04	*	**< LOD**	**.072** (.056-.089)	**.144** (.118-.174)	**.222** (.170-.305)	952
Females	99-00	**.065** (.056-.077)	**< LOD**	**.150** (.120-.190)	**.380** (.300-.450)	**.560** (.420-.680)	992
	01-02**	**.062** (.057-.067)	**.050** (.040-.050)	**.130** (.110-.150)	**.320** (.260-.400)	**.570** (.450-.710)	1224
	03-04	**.051** (<LOD-.057)	**< LOD**	**.118** (.103-.130)	**.290** (.244-.319)	**.442** (.382-.661)	1007
Race/ethnicity							
Mexican Americans	99-00	**.098** (.080-.119)	**.090** (.070-.110)	**.240** (.200-.310)	**.580** (.390-.840)	**.910** (.580-1.37)	632
	01-02**	**.078** (.068-.091)	**.070** (.050-.080)	**.160** (.130-.210)	**.470** (.330-.700)	**1.01** (.620-1.32)	563
	03-04	**.064** (.051-.080)	**.057** (<LOD-.086)	**.139** (.124-.190)	**.331** (.191-.501)	**.521** (.297-.814)	460
Non-Hispanic blacks	99-00	*	**< LOD**	**.100** (.070-.140)	**.250** (.190-.290)	**.360** (.280-.460)	403
	01-02**	*	**< LOD**	**.070** (.050-.110)	**.220** (.120-.410)	**.410** (.190-1.05)	513
	03-04	*	**< LOD**	**.065** (.047-.083)	**.167** (.131-.214)	**.281** (.200-.404)	487
Non-Hispanic whites	99-00	*	**< LOD**	**.120** (.100-.140)	**.250** (.170-.340)	**.390** (.280-.510)	702
	01-02**	*	**< LOD**	**.090** (.080-.110)	**.210** (.180-.260)	**.350** (.250-.480)	1051
	03-04	*	**< LOD**	**.083** (.073-.096)	**.175** (.146-.220)	**.287** (.221-.372)	887

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.
**In survey period 2001-2002, each result has been multiplied by 1.5528. See the section "What's New" at the beginning of this *Report* for details.

hexachlorocyclohexane isomers as possibly carcinogenic to humans, and NTP classifies hexachlorocyclohexane isomers as reasonably anticipated to be human carcinogens. More information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA at: http://www.epa.gov/pesticides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Because of its longer half-life, *beta*-HCH may be detected in a higher percentage of the general population than are the other HCH isomers. Studies of general populations have shown declining *beta*-HCH levels since the 1970s (ATSDR, 2005; Kutz et al., 1991; Link et al., 2005; Radomski et al., 1971; Stehr-Green, 1989; Sturgeon et al., 1998). Additional factors associated with higher *beta*-HCH levels include rural residence, older age, male sex, and a diet that includes meat (Becker et al., 2002; Kutz et al., 1991; Stehr-Green, 1989).

In NHANES 1999-2000, 2001-2002, and 2003-2004, serum levels of lindane were generally below the limits of detection, which were considerably lower (as much as twentyfold) than mean levels reported in small studies of adults in Spain (Botella et al., 2004) and India (Bhatnagar et al., 2004). In recent years, studies in populations with environmental exposure have reported lindane levels below the limit of detection in most persons (Anderson et al., 1998; Bates et al., 2004; Becker et al., 2002). In population-based studies of New Zealand adults and German adults and children, the maximum and 95th percentile *beta*-HCH values, respectively, were similar to the 95th percentiles in this *Report*. In an earlier (1996-1997) sample of German children, aged 9-11 years, the 95th percentile of *beta*-HCH levels was twofold to threefold higher than the 95th percentile of 12-19 year olds in the comparable NHANES

Serum *gamma*-Hexachlorocyclohexane (Lindane) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1799
	01-02	*	< LOD	< LOD	< LOD	< LOD	2280
	03-04	*	< LOD	< LOD	< LOD	< LOD	1960
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	< LOD	< LOD	< LOD	593
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1139
	01-02	*	< LOD	< LOD	< LOD	< LOD	1522
	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	863
	01-02	*	< LOD	< LOD	< LOD	< LOD	1060
	03-04	*	< LOD	< LOD	< LOD	< LOD	952
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	936
	01-02	*	< LOD	< LOD	< LOD	< LOD	1220
	03-04	*	< LOD	< LOD	< LOD	< LOD	1008
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	< LOD	< LOD	563
	03-04	*	< LOD	< LOD	< LOD	< LOD	461
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	380
	01-02	*	< LOD	< LOD	< LOD	< LOD	509
	03-04	*	< LOD	< LOD	< LOD	< LOD	490
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	646
	01-02	*	< LOD	< LOD	< LOD	< LOD	1045
	03-04	*	< LOD	< LOD	< LOD	< LOD	884

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 14.5, 10.5, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

2001-2002 survey period (Link et al., 2005). In a small study of adults who consumed sport fish from the Great Lakes, the median *beta*-HCH levels were similar or slightly higher than the 95th percentile in this *Report* (Anderson et al., 1998). A study of Swedish women aged 54 years and older reported a median *beta*-HCH level that was slightly higher than the geometric mean for women reported in the NHANES 1999-2000 survey period (Glynn et al., 2003). *Beta*-HCH and lindane levels in workers involved in HCH production have been more than 1000-fold higher than the 95th percentile and limit of detection (lipid adjusted), respectively, in this *Report* (Nigam et al., 1986; Radomski et al., 1971).

Finding a measurable amount of HCH isomers in serum does not mean that the level of HCH isomers causes an adverse health effect. Biomonitoring studies on levels of HCH isomers provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of HCH isomers than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum *gamma*-Hexachlorocyclohexane (Lindane) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1799
	01-02	*	< LOD	< LOD	< LOD	< LOD	2280
	03-04	*	< LOD	< LOD	< LOD	< LOD	1960
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	< LOD	< LOD	< LOD	593
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1139
	01-02	*	< LOD	< LOD	< LOD	< LOD	1522
	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	863
	01-02	*	< LOD	< LOD	< LOD	< LOD	1060
	03-04	*	< LOD	< LOD	< LOD	< LOD	952
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	936
	01-02	*	< LOD	< LOD	< LOD	< LOD	1220
	03-04	*	< LOD	< LOD	< LOD	< LOD	1008
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	< LOD	< LOD	563
	03-04	*	< LOD	< LOD	< LOD	< LOD	461
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	380
	01-02	*	< LOD	< LOD	< LOD	< LOD	509
	03-04	*	< LOD	< LOD	< LOD	< LOD	490
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	646
	01-02	*	< LOD	< LOD	< LOD	< LOD	1045
	03-04	*	< LOD	< LOD	< LOD	< LOD	884

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Mirex

CAS No. 2385-85-5

General Information

Mirex has not been produced or used in the U.S. since 1977. Formerly, its major uses were as a flame retardant additive and as a pesticide to kill fire ants and yellow jackets in the southeastern U.S., where it was applied directly to soil and by aerial spraying. Mirex binds strongly to soil, where it has a half-life of 12 years; it is a highly persistent chemical in the environment. Mirex has been detected in air, soil, sediments, water, aquatic organisms, animals, and foods. Mirex contamination of Lake Ontario and adjacent waterways has been well documented (ATSDR, 1995). The most likely sources of human exposure to mirex are eating fish from contaminated water or living in areas with soil contaminated by historic mirex manufacturing, disposal, or pesticide application. Some states and the U.S. EPA have issued public health advisories or warnings that fish from contaminated lakes and rivers may contain mirex. Occupational exposure is limited to workers at sites where mirex contamination is present.

Mirex is absorbed through the skin and from the gastrointestinal tract, after which it is widely distributed in the body and stored in fat. Ingested mirex that is not absorbed is eliminated in the feces within about 48 hours. Mirex is not metabolized in the body. In studies conducted in the 1970’s and 1980’s, mirex was detected in human adipose samples, especially those from persons living in the southeastern U.S. (Kutz et al., 1985, 1991). Mirex can cross the placenta and be excreted in breast milk, resulting in exposure to newborns and nursing infants.

Human health effects from mirex at low environmental doses or at biomonitored levels from low environmental

Serum Mirex (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1853
	01-02	*	< LOD	< LOD	15.8 (<LOD-73.7)	57.1 (13.2-230)	2257
	03-04	*	< LOD	< LOD	8.40 (<LOD-13.0)	13.2 (7.90-29.6)	1951
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	659
	01-02	*	< LOD	< LOD	< LOD	< LOD	728
	03-04	*	< LOD	< LOD	< LOD	< LOD	592
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1194
	01-02	*	< LOD	< LOD	19.6 (<LOD-108)	71.0 (14.6-305)	1529
	03-04	*	< LOD	< LOD	9.10 (<LOD-15.6)	15.4 (8.10-37.1)	1359
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	887
	01-02	*	< LOD	< LOD	16.1 (<LOD-65.6)	50.8 (12.3-225)	1052
	03-04	*	< LOD	< LOD	9.70 (<LOD-15.4)	15.5 (9.70-24.4)	949
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	966
	01-02	*	< LOD	< LOD	15.0 (<LOD-108)	63.0 (12.0-374)	1205
	03-04	*	< LOD	< LOD	< LOD	11.6 (<LOD-31.3)	1002
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	617
	01-02	*	< LOD	< LOD	< LOD	< LOD	548
	03-04	*	< LOD	< LOD	< LOD	< LOD	459
Non-Hispanic blacks	99-00	*	< LOD	< LOD	15.5 (<LOD-42.2)	39.5 (<LOD-115)	398
	01-02	*	< LOD	13.7 (<LOD-47.3)	51.3 (15.4-230)	153 (30.5-425)	500
	03-04	*	< LOD	< LOD	18.1 (8.70-40.8)	40.3 (15.5-82.7)	484
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	688
	01-02	*	< LOD	< LOD	15.1 (<LOD-104)	66.7 (12.5-291)	1049
	03-04	*	< LOD	< LOD	< LOD	11.6 (<LOD-23.4)	884

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 14.6, 10.5, and 7.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

exposures are unknown. Laboratory animals fed high doses developed liver enlargement and liver tumors; reproductive toxicity included decreased fertility and testicular damage. In addition, developmental abnormalities including cataracts and edema in the offspring have been reported (ATSDR, 1995; Smith, 1991). The U.S. EPA has established environmental standards for mirex, and the FDA monitors foods for pesticide residue and has established an action level for mirex in fish tissue. IARC classifies mirex as possibly carcinogenic to humans, and NTP classifies mirex as reasonably anticipated to be a human carcinogen. More information about external exposure (i.e., environmental levels) and health effects is available from the ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

In the NHANES 1999-2000, 2001-2002, and 2003-2004 subsamples, as well as in a subsample of NHANES II (1976-1980) participants, serum mirex levels were generally below the limits of detection (Stehr-Green, 1989). Fishermen in New York who consumed Great Lakes sport fish had median levels of lipid-adjusted serum mirex that were lower than the 95th percentile value among males the NHANES 2001-2002 subsample (Bloom et al., 2005). In samples obtained between 1994 and 1997, Inuit mothers from three Arctic areas had geometric mean serum mirex levels that were threefold to sevenfold higher than non-Inuit mother from other Arctic regions. The geometric mean mirex levels of the Inuit mothers were 8, 7.8, and 4.7 ng/g of lipid, which is approximately twofold to threefold lower than the 90th percentile for females in the NHANES 2001-2002 subsample but similar to 95th percentile for females in the NHANES 2003-2004 subsample (Van Oostdam et al., 2004).

Finding a measurable amount of mirex in serum does not mean that the level of mirex causes an adverse health

Serum Mirex (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1853
	01-02	*	< LOD	< LOD	.100 (<LOD-.470)	.410 (.080-1.73)	2257
	03-04	*	< LOD	< LOD	.054 (<LOD-.084)	.093 (.052-.170)	1951
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	659
	01-02	*	< LOD	< LOD	< LOD	< LOD	728
	03-04	*	< LOD	< LOD	< LOD	< LOD	592
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1194
	01-02	*	< LOD	< LOD	.140 (<LOD-.690)	.470 (.090-1.92)	1529
	03-04	*	< LOD	< LOD	.059 (<LOD-.102)	.106 (.053-.215)	1359
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	887
	01-02	*	< LOD	< LOD	.110 (<LOD-.470)	.370 (.090-1.37)	1052
	03-04	*	< LOD	< LOD	.064 (<LOD-.106)	.108 (.062-.170)	949
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	966
	01-02	*	< LOD	< LOD	.090 (<LOD-.510)	.430 (.070-1.79)	1205
	03-04	*	< LOD	< LOD	< LOD	.077 (<LOD-.170)	1002
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	617
	01-02	*	< LOD	< LOD	< LOD	< LOD	548
	03-04	*	< LOD	< LOD	< LOD	< LOD	459
Non-Hispanic blacks	99-00	*	< LOD	< LOD	.090 (<LOD-.220)	.220 (<LOD-.450)	398
	01-02	*	< LOD	.090 (<LOD-.240)	.310 (.090-1.41)	1.08 (.170-3.02)	500
	03-04	*	< LOD	< LOD	.112 (.055-.268)	.256 (.089-.635)	484
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	688
	01-02	*	< LOD	< LOD	.100 (<LOD-.610)	.450 (.080-1.79)	1049
	03-04	*	< LOD	< LOD	< LOD	.079 (<LOD-.174)	884

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

effect. Biomonitoring studies on levels of mirex provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of mirex than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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2,4,5-Trichlorophenol

CAS No. 95-95-4

2,4,6-Trichlorophenol

CAS No. 88-06-2

Metabolites of Organochlorine Pesticides and Other Environmental Chemicals

General Information

The chlorophenols, 2,4,5-trichlorophenol (2,4,5-TCP) and 2,4,6-trichlorophenol (2,4,6-TCP), are metabolites of several organochlorine chemicals, including hexachlorobenzene and hexachlorocyclohexanes. Historically, 2,4,5-TCP and 2,4,6-TCP were used as intermediates in the production of certain pesticides; 2,4,6-TCP was also used as a wood preservative and may still be used in production of some fungicides (ATSDR, 1999). Trichlorophenols are no longer manufactured commercially, but they may be produced as by-products during manufacturing of other chlorinated aromatic compounds. Formation of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin occurs during the synthesis of 2,4,5-trichlorophenol. Small amounts of trichlorophenols also can be produced during combustion of natural materials and the chlorination of drinking water or waste water that contains phenols. Environmental sources of these compounds include industrial discharges or run off from pesticide facilities or disposal sites. Both chemicals have been detected in air, surface water, soils, and sediments; however, recent sampling of U.S. public drinking water systems did not detect 2,4,6-TCP in any of the samples (U.S. EPA, 2006). Trichlorophenols have been detected in fish taken from waters near waste water treatment and industrial discharges (ATSDR, 1999).

General population exposure may occur by ingesting contaminated food or water and by inhaling contaminated air. Exposure to trichlorophenols also may result from metabolism of lindane, hexachlorobenzene, other organochlorines, and polychlorinated benzenes (Kohil et al., 1976). Occupational exposures, usually at herbicide production or waste incineration facilities, may occur by inhalation or dermal routes. Such workers would probably

Urinary 2,4,5-Trichlorophenol

Metabolite of Several Organochlorine Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**1.40** (1.00-3.20)	**5.40** (2.50-16.0)	**16.0** (4.30-40.0)	1994
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.42** (<LOD-8.27)	2497
Age group							
6-11 years	99-00	*	**< LOD**	**1.40** (1.10-3.40)	**4.80** (2.30-11.0)	**11.0** (4.20-36.0)	482
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.42** (<LOD-12.7)	570
12-19 years	99-00	*	**< LOD**	**1.60** (.940-3.72)	**5.40** (2.50-25.0)	**24.0** (3.80-41.0)	681
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.19** (<LOD-6.63)	815
20-59 years	99-00	*	**< LOD**	**1.40** (.980-3.30)	**5.40** (2.40-18.0)	**18.0** (4.30-44.0)	831
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.71** (<LOD-8.27)	1112
Gender							
Males	99-00	*	**< LOD**	**1.40** (.980-3.80)	**5.40** (2.60-8.40)	**11.0** (5.30-27.0)	973
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**5.57** (<LOD-15.8)	1178
Females	99-00	*	**< LOD**	**1.50** (1.00-3.20)	**6.50** (2.30-27.0)	**21.0** (3.20-71.0)	1021
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1319
Race/ethnicity							
Mexican Americans	99-00	*	**.950** (<LOD-1.30)	**1.80** (1.30-3.50)	**8.60** (4.60-18.0)	**21.0** (8.90-33.0)	696
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**14.9** (<LOD-121)	661
Non-Hispanic blacks	99-00	*	**< LOD**	**1.30** (.900-2.20)	**5.00** (2.00-8.40)	**9.00** (3.50-63.0)	521
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.31** (<LOD-9.03)	696
Non-Hispanic whites	99-00	*	**< LOD**	**1.50** (.920-3.60)	**4.60** (2.40-11.0)	**9.20** (4.30-27.0)	603
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.71** (<LOD-8.27)	939

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.9 and 0.9.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

be exposed to mixtures of chlorophenols, in addition to dioxins, furans, and other chlorinated compounds. However, recent small studies have not demonstrated increased exposure to trichlorophenols in workers who dredged contaminated soils or incinerated waste materials (Agramunt et al., 2003; Radon et al., 2004).

Human health effects from 2,4,5-TCP or 2,4,6-TCP at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Laboratory animals chronically fed high doses of 2,4,6-TCP had increased rates of hepatic tumors, leukemias, and lymphomas. At lower doses, animals showed hepatocellular abnormalities. Neither 2,4,5-TCP nor 2,4,6-TCP were developmental or reproductive toxicants in animals (ATSDR 1999). IARC classifies combined exposures to polychlorophenols, which includes trichlorophenols, as being possibly carcinogenic to humans. IARC considers the experimental evidence for animal carcinogenicity inadequate for 2,4,5-TCP and limited for 2,4,6-TCP. NTP classifies 2,4,6-TCP as reasonably anticipated to be a human carcinogen. More information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

In the NHANES 1999-2000 and 2001-2002 subsamples, urinary 2,4,6-TCP levels at the 95th percentile were up to eight times higher than 3.3 µg/L in a nonrandom subsample from NHANES III (Hill et al., 1995) and up to 19 times higher than the 95th percentile value of 1.3 µg/L reported in German adults aged 18-69 years (Becker et al., 2003). Among 6-11 year old children in NHANES 1999-2000, the 95th percentile urinary 2,4,6-TCP level was approximately eight times higher than the corresponding percentile in a small group of 2-6 year old children living near an herbicide manufacturing facility: 33 versus 4 µg/L (Hill et al., 1989). In the same 2-6 year old children, the 95th percentile urinary 2,4,5-TCP, 7.0 µg/L, was similar to the corresponding percentile for 6-11 year olds in NHANES 1999-2000 (Hill et al., 1989). The 95th percentiles for 2,4,5-TCP among adults in this *Report* and in a nonrandom subsample from NHANES III (Hill et al., 1995) were similar, but almost twenty times higher than 95th percentile values reported in German adults aged 18-69 years (Becker et al., 2003).

Urinary 2,4,5-Trichlorophenol (creatinine corrected)

Metabolite of Several Organochlorine Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**2.36** (1.53-3.16)	**5.57** (3.24-11.2)	**11.9** (5.00-19.6)	1994
	01-02	*	< LOD	< LOD	< LOD	**4.57** (<LOD-7.11)	2496
Age group							
6-11 years	99-00	*	< LOD	**2.29** (1.19-4.78)	**5.86** (3.83-12.4)	**12.8** (5.28-25.4)	482
	01-02	*	< LOD	< LOD	< LOD	**5.82** (<LOD-32.5)	570
12-19 years	99-00	*	< LOD	**1.44** (.920-2.50)	**3.80** (1.93-11.2)	**11.2** (2.62-20.1)	681
	01-02	*	< LOD	< LOD	< LOD	**2.75** (<LOD-6.74)	814
20-59 years	99-00	*	< LOD	**2.46** (1.60-3.24)	**5.75** (3.37-11.5)	**11.7** (4.78-19.6)	831
	01-02	*	< LOD	< LOD	< LOD	**4.57** (<LOD-7.11)	1112
Gender							
Males	99-00	*	< LOD	**1.67** (1.02-3.15)	**4.24** (3.05-8.02)	**9.55** (4.13-13.6)	973
	01-02	*	< LOD	< LOD	< LOD	**4.68** (<LOD-8.37)	1178
Females	99-00	*	< LOD	**2.67** (1.79-4.00)	**7.95** (3.05-17.8)	**16.3** (5.00-29.3)	1021
	01-02	*	< LOD	< LOD	< LOD	< LOD	1318
Race/ethnicity							
Mexican Americans	99-00	*	**.980** (<LOD-1.33)	**2.49** (1.68-4.24)	**6.90** (4.19-12.4)	**12.4** (6.88-16.9)	696
	01-02	*	< LOD	< LOD	< LOD	**12.1** (<LOD-58.0)	661
Non-Hispanic blacks	99-00	*	< LOD	**1.16** (.820-2.31)	**3.43** (2.20-6.32)	**7.69** (2.69-18.2)	521
	01-02	*	< LOD	< LOD	< LOD	**2.81** (<LOD-9.17)	695
Non-Hispanic whites	99-00	*	< LOD	**2.44** (1.53-3.24)	**4.78** (3.47-8.43)	**9.64** (4.27-17.8)	603
	01-02	*	< LOD	< LOD	< LOD	**4.73** (<LOD-8.37)	939

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

A small study of adults who ate Great Lakes sport fish reported a mean urine 2,4,5-TCP level of 0.7 µg/L, similar to the limit of detection for this *Report* (Anderson et al., 1998). Urinary 2,4,5-TCP and 2,4,6-TCP were monitored in a group of hazardous waste incinerator workers from 1999-2002. Mean values of 2,4,5-TCP (0.2-0.6 µg/g creatinine) and 2,4,6-TCP (0.7-3.5 µg/g creatinine) were similar to the limit of detection for 2,4,5-TCP and to the median 2,4,6-TCP values, respectively, for males in NHANES 1999-2002 (Agramunt et al., 2003). In harbor workers exposed to chlorophenol-contaminated river silt, the median urinary 2,4,6-TCP level, 0.36 µg/g creatinine, was about six times lower than the median urinary levels for males in this *Report* (Radon et al., 2004). Sawmill workers exposed to chlorophenol wood preservatives had urinary 2,4,6-TCP levels that were as much as 450 times higher than the median level among adults in the NHANES 1999-2000 subsample (Pekari et al., 1991).

Finding a measurable amount of 2,4,5-TCP or 2,4,6-TCP in urine does not mean that the level of 2,4,5-TCP or 2,4,6-TCP causes an adverse health effect. Biomonitoring studies on levels of 2,4,5-TCP and 2,4,6-TCP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of 2,4,5-TCP or 2,4,6-TCP than are found in the general population. Biomonitoring data will also help scientists plan and conduct research about 2,4,5-TCP or 2,4,6-TCP exposure and health effects.

Urinary 2,4,6-Trichlorophenol

Metabolite of Several Organochlorine Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**2.85** (2.55-3.18)	**2.50** (2.40-2.70)	**4.90** (3.80-7.70)	**15.0** (7.80-25.0)	**25.0** (15.0-44.0)	1989
	01-02	*	**1.68** (<LOD-2.44)	**5.95** (4.89-6.63)	**10.8** (9.98-11.7)	**14.9** (13.4-17.9)	2503
Age group							
6-11 years	99-00	**4.47** (3.36-5.95)	**3.80** (2.70-6.40)	**11.0** (4.80-20.0)	**24.0** (14.0-38.0)	**33.0** (20.5-46.0)	481
	01-02	**3.08** (2.52-3.76)	**3.00** (1.91-4.32)	**7.79** (5.73-9.99)	**13.4** (10.6-17.3)	**19.2** (14.1-25.3)	574
12-19 years	99-00	**3.56** (3.00-4.23)	**3.00** (2.60-3.70)	**6.00** (4.30-11.0)	**20.4** (9.60-37.0)	**37.0** (20.0-54.0)	678
	01-02	**3.24** (2.74-3.84)	**3.26** (2.33-4.40)	**7.49** (6.45-9.40)	**13.6** (11.0-18.2)	**19.4** (17.3-26.6)	820
20-59 years	99-00	**2.52** (2.23-2.85)	**2.40** (2.10-2.45)	**4.20** (3.50-5.30)	**12.0** (6.00-21.0)	**21.0** (11.0-41.0)	830
	01-02	*	**< LOD**	**4.89** (3.70-6.28)	**9.66** (8.72-10.7)	**13.3** (11.8-15.2)	1109
Gender							
Males	99-00	**2.92** (2.58-3.31)	**2.60** (2.40-2.90)	**5.20** (3.90-8.10)	**15.0** (8.48-26.0)	**26.0** (15.0-38.0)	970
	01-02	*	**2.36** (1.70-3.04)	**6.65** (5.98-7.53)	**12.1** (10.8-13.1)	**17.0** (13.6-22.2)	1178
Females	99-00	**2.78** (2.35-3.28)	**2.40** (2.30-2.60)	**4.80** (3.40-7.59)	**16.0** (6.40-32.0)	**25.0** (14.0-50.0)	1019
	01-02	*	**< LOD**	**4.69** (3.59-6.09)	**9.75** (8.25-11.6)	**13.3** (11.7-16.6)	1325
Race/ethnicity							
Mexican Americans	99-00	**2.70** (2.20-3.32)	**2.70** (2.10-3.10)	**4.90** (4.20-6.70)	**15.0** (8.20-23.0)	**23.0** (14.0-43.0)	694
	01-02	*	**2.07** (<LOD-3.23)	**5.31** (3.95-6.54)	**11.4** (8.51-12.8)	**15.6** (12.6-19.8)	677
Non-Hispanic blacks	99-00	**3.14** (2.40-4.12)	**2.80** (2.10-3.40)	**6.60** (3.40-14.0)	**18.0** (9.30-33.0)	**32.0** (16.0-68.0)	519
	01-02	**2.78** (2.18-3.53)	**2.58** (1.32-4.02)	**6.45** (5.09-7.67)	**11.1** (8.87-14.9)	**17.9** (11.8-24.7)	696
Non-Hispanic whites	99-00	**2.74** (2.46-3.06)	**2.45** (2.30-2.80)	**4.60** (3.80-6.60)	**13.0** (6.60-21.0)	**21.0** (12.0-37.0)	602
	01-02	*	**1.57** (<LOD-2.20)	**6.10** (5.01-6.65)	**10.7** (9.67-12.3)	**14.7** (13.3-17.9)	931

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 1.0 and 1.3.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary 2,4,6-Trichlorophenol (creatinine corrected)

Metabolite of Several Organochlorine Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**2.54** (2.30-2.81)	**2.38** (2.14-2.68)	**4.91** (3.83-6.49)	**12.1** (8.67-17.0)	**21.2** (13.6-31.5)	1989
	01-02	*	**2.43** (<LOD-2.75)	**4.38** (4.18-4.78)	**8.33** (7.10-9.26)	**11.6** (9.25-15.6)	2502
Age group							
6-11 years	99-00	**4.82** (3.87-6.00)	**4.71** (3.41-6.53)	**11.5** (7.63-15.3)	**22.7** (14.1-32.6)	**32.6** (22.7-36.8)	481
	01-02	**4.00** (3.28-4.87)	**4.01** (3.29-4.81)	**8.26** (6.16-10.4)	**13.9** (9.51-21.5)	**21.2** (12.9-64.1)	574
12-19 years	99-00	**2.40** (2.08-2.78)	**2.33** (1.95-2.68)	**4.35** (3.13-6.00)	**11.6** (6.94-13.6)	**14.4** (11.3-23.6)	678
	01-02	**2.51** (2.18-2.90)	**2.78** (2.09-3.17)	**4.52** (3.83-5.92)	**8.29** (6.81-9.89)	**12.5** (8.73-22.8)	819
20-59 years	99-00	**2.32** (2.04-2.63)	**2.22** (1.89-2.56)	**4.25** (3.38-5.63)	**10.0** (6.72-16.9)	**19.6** (10.9-34.4)	830
	01-02	*	**< LOD**	**4.05** (3.66-4.38)	**7.10** (6.43-7.72)	**9.82** (8.53-11.9)	1109
Gender							
Males	99-00	**2.24** (1.99-2.53)	**2.15** (1.82-2.42)	**4.41** (3.56-5.88)	**10.8** (7.04-16.4)	**18.0** (11.5-28.5)	970
	01-02	*	**2.23** (1.91-2.65)	**4.22** (3.77-4.73)	**8.05** (6.70-9.17)	**12.2** (8.79-17.7)	1178
Females	99-00	**2.88** (2.49-3.33)	**2.63** (2.25-2.96)	**5.53** (3.88-7.23)	**13.3** (9.65-21.9)	**25.1** (13.3-37.0)	1019
	01-02	*	**< LOD**	**4.58** (4.19-5.11)	**8.40** (7.27-9.51)	**10.9** (9.26-13.6)	1324
Race/ethnicity							
Mexican Americans	99-00	**2.43** (2.06-2.87)	**2.50** (2.22-2.82)	**5.44** (3.87-7.10)	**10.8** (8.46-14.9)	**18.4** (12.1-21.8)	694
	01-02	*	**2.22** (<LOD-2.88)	**4.25** (3.47-5.76)	**8.15** (6.21-11.1)	**11.6** (9.63-13.9)	677
Non-Hispanic blacks	99-00	**2.13** (1.65-2.76)	**1.90** (1.60-2.52)	**4.00** (2.76-8.02)	**11.6** (5.32-19.7)	**19.5** (10.9-29.5)	519
	01-02	**1.98** (1.55-2.52)	**2.02** (1.48-2.76)	**3.83** (3.17-4.88)	**6.52** (5.50-8.06)	**9.91** (7.14-13.2)	695
Non-Hispanic whites	99-00	**2.59** (2.33-2.88)	**2.42** (2.20-2.77)	**4.87** (3.83-6.06)	**11.2** (7.62-15.5)	**19.6** (12.9-32.8)	602
	01-02	*	**2.63** (<LOD-2.88)	**4.60** (4.29-4.98)	**8.56** (7.22-9.65)	**12.0** (9.25-17.1)	931

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Organophosphorus Insecticides: Dialkyl Phosphate Metabolites

General Information

Organophosphorus insecticides, which are active against a broad spectrum of insects, have accounted for a large share of all insecticides used in the United States. Although organophosphorus insecticides are still used for insect control on many food crops, most residential uses have been phased out in the United States as a result of implementation of the Food Quality Protection Act of 1996. Certain organophosphorus insecticides (e.g., malathion, naled) are also registered for public health applications (e.g., mosquito control) in the United States. An estimated 73 million pounds of organophosphorus insecticides (70% of all insecticides) were used in the United States in 2001, with usage declining 45% since 1980 (U.S. EPA, 2004). Approximately 40 organophosphorus insecticides in a wide variety of formulations are registered for use in the United States by the U.S. EPA. In general, the various organophosphorus insecticides demonstrate low vapor pressures (with some exceptions), slight to moderate water solubility, moderate to high soil binding, widely varying degrees of soil leaching or runoff potential, and a low persistence in the environment.

General population exposure to organophosphorus insecticides may occur by ingesting contaminated food and from hand-to-mouth contact with surfaces containing organophosphorus insecticides; less common routes include inhalation and dermal contact. In general, the organophosphorus insecticides have better gastrointestinal than dermal absorption. Mammalian elimination half-lives can range from hours to weeks. The thiophosphate type organophosphorus insecticides (e.g., chlorpyriphos) are initially metabolized to the more toxic “oxon” form. Most organophosphorus insecticides undergo hydrolysis with excretion of major hydrolytic metabolites in the urine. Estimated intakes by the general population are usually considered below regulatory thresholds though concerns have been raised about some organophosphrus insecticides because of unique routes of exposures and intakes in infants and children (NRC, 1993). Farm workers, gardeners, florists, pesticide applicators, and manufacturers of these insecticides may have greater exposure than the general population. Many states have programs to monitor

Pesticide (CAS number)	**Dimethyl-phosphate** (813-79-5)	**Dimethylthio-phosphate** (1112-38-5)	**Dimethyldithio-phosphate** (756-80-9)	**Diethyl-phosphate** (598-02-7)	**Diethylthio-phosphate** (2465-65-8)	**Diethyldithio-phosphate** (298-06-6)
Azinphos methyl	•	•	•			
Chlorethoxyphos				•	•	
Chlorpyrifos				•	•	
Chlorpyrifos methyl	•	•				
Coumaphos				•	•	
Dichlorvos (DDVP)	•					
Diazinon				•	•	
Dicrotophos	•					
Dimethoate	•	•	•			
Disulfoton				•	•	•
Ethion				•	•	•
Fenitrothion	•	•				
Fenthion	•	•				
Isazaphos-methyl	•	•				
Malathion	•	•	•			
Methidathion	•	•	•			
Methyl parathion	•	•				
Naled	•					
Oxydemeton-methyl	•	•				
Parathion				•	•	
Phorate				•	•	•
Phosmet	•	•	•			
Pirimiphos-methyl	•	•				
Sulfotepp				•	•	
Temephos	•	•				
Terbufos				•	•	•
Tetrachlorvinphos	•					

cholinesterase activity in the blood of pesticide applicators as part of monitoring exposure to organophosphorus insecticides. The U.S. FDA, USDA, U.S. EPA, and OSHA have developed criteria on allowable levels of these chemicals in foods, the environment, and the workplace.

The acute high dose effects of the organophosphorus insecticides from intentional and unintentional overdoses or from high-dose worker exposures are well known and include neurological dysfunction that results from the inhibition of the enzyme acetylcholinesterase leading to excess acetylcholine in the central and peripheral nervous systems. Acute symptoms include nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. Mild to severe peripheral neuropathies and residual deficits in neurocognitive functioning can persist following acute poisonings (London et al., 1998; Rosenstock et al., 1991; Savage et al., 1988). Chronic exposures studied in farmers and insecticide applicators, who have neither past acute poisoning or significant reduction in blood cholinesterase activity, have shown possible subtle or subclinical neurological effects, though various study results are inconsistent (Albers et al., 2004; Daniell et al., 1992.; Engel et al., 1998; Farahat et al., 2003; Fiedler et al., 1997; Jamal et al., 2002; Maizlish et al., 1987; Peiris-John et al., 2002; Pilkington et al., 2001; Rodnitzky et al., 1975; Rothlein et al., 2006; Stephens et al., 1995; Stokes et al., 1995; Young et al., 2005). Animal studies at high doses generally demonstrate the effects of inhibition of acetylcholinesterase mentioned above for acute poisoning in humans, as well as mechanistically-related neurodevelopmental and reproductive effects (Astroff et al., 1998*a* and 1998*b*; Prendergast et al., 1998). Few animal studies have addressed the potential for low environmental doses to produce non-cholinergic effects (i.e., without inhibition of acetylcholinesterase). Additional information about insecticides is available from U.S. EPA at: http://www.epa.gov/pesticides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

About 75% of registered organophosphorus insecticides are metabolized in the body to measurable dialkyl phosphate metabolites. The dialkyl phosphate metabolites do not inhibit acetylcholinesterase and are not considered toxic, but are regarded as markers of exposure to organophosphorus insecticides. Dialkyl phosphate metabolites can be present in urine after low level exposures to organophosphorus insecticides that do not cause clinical symptoms or inhibition of cholinesterase activity (Davies and Peterson, 1997; Franklin et al., 1981). Measurement of these metabolites reflects recent exposure, predominantly in the previous few days. Dialkyl phosphates may also occur in the environment as a result of degradation of organophosphorus insecticides (Lu et al., 2005), and therefore, the presence in a person's urine may reflect exposure to the metabolite itself.

Generally, six urinary dialkyl phosphate metabolites of organophosphorus insecticides are measured in this *Report* and other research studies: dimethylphosphate (DMP); dimethylthiophosphate (DMTP); dimethyldithiophosphate (DMDTP); diethylphosphate (DEP); diethylthiophosphate (DETP); and diethyldithiophosphate (DEDTP). The table shows the six urinary metabolites and the parent organophosphorus insecticides responsible for these metabolites. For example, chlorpyrifos is metabolized to both diethylphosphate and diethythiophosphate. Each of the six urinary dialkyl phosphate metabolites can be produced from the metabolism of more than one organophosphorus insecticide. Therefore, the presence of one or more dialkyl phosphate metabolites without additional information cannot be linked to exposure to a specific organophosphorus insecticide.

Biomonitoring Information

Urinary dialkyl phosphate levels reflect recent exposure. In nationally representative subsamples of the U.S. population from NHANES 1999-2000 and 2001-2002 (CDC, 2005), geometric mean urinary dialkyl phosphate levels were generally lower than levels reported in smaller studies of children and adults in Italy and Germany (Aprea et al., 2000; Aprea et al., 1996; Heudorf and Angerer, 2001; Saieva et al., 2004). In these studies and the NHANES subsamples, children have slightly higher levels than adults. Diet influences the measured levels of urinary dialkyl phosphates. For example, subjects ingesting "organically-grown" foods were shown to have lower levels of urinary dialkyl phosphates than subjects eating a conventional diet (Curl et al., 2003). Also, urinary levels in children of farm workers and non-farm workers have been reported to correlate weakly with environmental dust levels of particular insecticides in some, but not all, studies (Bouvier et al., 2006; Curl et al., 2003; Rothlein et al., 2006).

Measurements of dialkyl phosphates in urine have been used to document exposure of farmers, agricultural workers, pest-control workers, and others to organophosphorus insecticides (Davies and Peterson, 1997; Franklin et al., 1981; Krieger and Dinoff, 2000; Takamiya, 1994). In some of these occupational studies, reported levels of urinary dialkyl phosphates may exceed levels seen in the general population by up to fiftyfold, though in general, worker levels are only moderately higher. Urinary levels of dialkyl phosphate metabolites vary with the type of field application, seasonal use of the parent insecticide, and demonstrate substantial variability when measured over multiple times of day and over multiple days, which may reflect changes in exposure, collection timing, and elimination kinetics (Kissel et al., 2005; Koch et al., 2002; Lambert et al., 2005; Petchuay et al., 2006).

Children and pregnant family members of farm workers were reported to have median levels of many urinary dialkyl phosphates that were either similar or slightly higher (Arcury et al., 2006; Bradman et al., 2005) than those presented in U.S. representative subsamples from NHANES 1999-2000 and 2001-2002 (CDC, 2005), except for one study in which DMTP levels were up to fourteenfold higher depending on the season and the type of crop application (Lambert et al., 2005). Also, estimates of dose or intake calculated from urinary dialkyl phosphate levels in studies of pregnant women in one agricultural community (Castorina et al., 2003) and in another study of workers exposed on reentry to treated orchards (Fenske et al., 2003) generally did not exceed doses considered to be safe. Estimates of dose or intake for the general U.S. population as calculated from urinary dialkyl phosphate measurements were below environmental dose estimates based on multiple routes of exposure (Duggan et al., 2003).

Information is limited with regard to associations between levels of urinary dialkyl phosphates and any health effects. Summed levels of urinary dialkyl phosphates in prenatal samples from mothers of neonates living in an agricultural community were associated with subtle changes in one of seven domains of neurophysiologic neonatal testing during one restricted postnatal period of time (Young et al., 2005). In a study of farm workers, median urinary levels of DMTP and DMDTP were more than twentyfold higher than median levels in the U.S. population (CDC, 2005), and these higher levels were associated with a few subtle neurobehavioral test results (Rothlein et al., 2006).

Finding a measurable amount of dialkyl phosphate metabolites in urine does not mean that the level of dialkyl phosphate metabolites causes an adverse health effect. Biomonitoring studies of dialkyl phosphate metabolites provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of organophosphorus pesticides than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Diethylphosphate (DEP)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.03** (.670-1.58)	**1.20** (.750-1.70)	**3.20** (2.30-4.80)	**7.60** (5.00-12.0)	**13.0** (7.70-23.0)	1949
	01-02	*	**< LOD**	**2.76** (2.42-3.16)	**6.33** (5.68-7.46)	**11.4** (9.15-12.5)	2520
	03-04	*	**< LOD**	**4.54** (3.38-5.97)	**10.2** (9.00-12.1)	**15.7** (14.1-17.2)	1931
Age group							
6-11 years	99-00	**1.32** (.757-2.29)	**1.50** (.860-2.60)	**4.50** (2.10-7.90)	**11.0** (4.80-24.0)	**16.0** (8.50-36.0)	471
	01-02	*	**.290** (<LOD-1.04)	**3.45** (2.36-4.47)	**9.56** (6.33-18.0)	**20.0** (9.44-38.2)	576
	03-04	*	**< LOD**	**5.13** (2.48-7.94)	**10.9** (8.08-15.9)	**16.1** (10.9-18.5)	308
12-19 years	99-00	**1.21** (.758-1.94)	**1.40** (.970-2.10)	**3.70** (2.40-5.50)	**8.00** (4.70-19.0)	**20.0** (8.00-27.0)	664
	01-02	*	**< LOD**	**2.86** (1.96-3.95)	**7.58** (5.71-9.15)	**11.0** (9.35-12.4)	822
	03-04	*	**.530** (<LOD-2.32)	**5.80** (4.34-7.67)	**14.8** (9.12-19.8)	**20.8** (14.8-32.7)	701
20-59 years	99-00	**.955** (.623-1.47)	**1.10** (.700-1.60)	**3.00** (1.80-4.80)	**7.30** (4.70-11.0)	**11.0** (6.80-22.0)	814
	01-02	*	**< LOD**	**2.71** (2.34-3.12)	**5.79** (5.05-7.21)	**10.4** (7.43-12.3)	1122
	03-04	*	**< LOD**	**4.37** (3.02-5.81)	**9.74** (8.35-11.3)	**14.2** (11.5-16.2)	922
Gender							
Males	99-00	**1.11** (.717-1.73)	**1.20** (.810-1.70)	**3.80** (2.50-5.00)	**8.00** (5.00-19.0)	**19.0** (7.20-30.0)	952
	01-02	*	**< LOD**	**3.13** (2.44-3.53)	**6.99** (5.79-7.80)	**11.5** (8.98-12.4)	1187
	03-04	*	**< LOD**	**4.85** (3.26-6.51)	**11.1** (9.56-13.8)	**17.2** (14.2-20.8)	928
Females	99-00	**.954** (.599-1.52)	**1.20** (.620-1.70)	**2.90** (1.90-4.80)	**7.50** (4.60-11.0)	**11.0** (7.40-16.0)	997
	01-02	*	**.290** (<LOD-.780)	**2.58** (2.17-3.02)	**5.93** (4.55-8.19)	**10.4** (7.27-15.1)	1333
	03-04	*	**< LOD**	**4.39** (3.23-5.97)	**9.39** (8.07-10.8)	**13.5** (11.3-15.9)	1003
Race/ethnicity							
Mexican Americans	99-00	**1.22** (.740-2.01)	**1.20** (.840-1.80)	**4.10** (2.20-7.00)	**11.0** (6.40-19.0)	**18.0** (12.0-27.0)	672
	01-02	*	**.600** (<LOD-1.63)	**3.10** (2.27-3.72)	**6.26** (5.00-7.82)	**11.2** (7.82-12.3)	678
	03-04	*	**1.08** (<LOD-2.81)	**5.58** (3.57-7.61)	**10.8** (8.35-16.1)	**17.7** (12.0-28.4)	473
Non-Hispanic blacks	99-00	**1.56** (1.13-2.14)	**1.60** (1.40-1.80)	**4.30** (2.90-5.80)	**10.0** (5.60-18.0)	**18.0** (8.00-27.0)	509
	01-02	*	**.890** (<LOD-2.42)	**4.61** (3.30-6.52)	**10.2** (7.40-14.0)	**15.4** (9.93-24.2)	696
	03-04	*	**.830** (<LOD-3.28)	**6.83** (5.26-8.80)	**12.2** (9.86-15.6)	**16.2** (14.1-23.2)	578
Non-Hispanic whites	99-00	**.981** (.579-1.66)	**1.10** (.490-2.10)	**3.30** (2.20-4.90)	**7.70** (4.70-14.0)	**14.0** (7.60-25.0)	595
	01-02	*	**< LOD**	**2.44** (2.08-2.91)	**5.56** (4.55-6.89)	**10.2** (7.52-11.9)	948
	03-04	*	**< LOD**	**4.16** (2.98-5.81)	**9.74** (8.40-11.6)	**14.8** (12.5-17.2)	752

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.2, 0.2, and 0.1, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Diethylphosphate (DEP) (creatinine corrected)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.924** (.608-1.41)	**.920** (.570-1.40)	**2.73** (1.68-4.60)	**7.94** (4.40-12.2)	**12.2** (8.00-19.6)	1949
	01-02	*	**< LOD**	**2.39** (2.06-2.69)	**5.23** (4.64-5.98)	**8.53** (6.94-10.2)	2519
	03-04	*	**< LOD**	**4.42** (3.45-5.74)	**9.02** (7.45-11.2)	**13.2** (10.5-16.1)	1928
Age group							
6-11 years	99-00	**1.43** (.870-2.34)	**1.47** (1.02-2.41)	**3.94** (2.20-8.57)	**10.5** (4.55-20.8)	**16.6** (10.5-32.7)	471
	01-02	*	**.890** (<LOD-1.76)	**4.02** (2.87-5.25)	**8.85** (6.88-15.6)	**18.4** (9.40-28.8)	576
	03-04	*	**< LOD**	**6.10** (3.79-9.03)	**11.9** (9.54-15.2)	**16.1** (11.9-28.3)	308
12-19 years	99-00	**.818** (.533-1.26)	**.790** (.560-1.25)	**2.35** (1.37-3.75)	**5.44** (2.82-14.4)	**12.4** (4.66-34.2)	664
	01-02	*	**< LOD**	**2.05** (1.54-2.67)	**4.40** (3.40-5.28)	**7.28** (5.28-9.75)	821
	03-04	*	**.440** (<LOD-2.05)	**4.47** (3.90-5.43)	**10.1** (7.10-13.5)	**14.7** (9.82-26.5)	699
20-59 years	99-00	**.883** (.574-1.36)	**.860** (.500-1.35)	**2.66** (1.54-4.95)	**7.37** (4.32-12.1)	**12.1** (8.00-17.5)	814
	01-02	*	**< LOD**	**2.28** (2.01-2.56)	**4.75** (3.92-5.83)	**7.37** (5.93-9.72)	1122
	03-04	*	**< LOD**	**4.29** (2.98-5.71)	**8.34** (6.09-11.3)	**11.9** (9.02-14.7)	921
Gender							
Males	99-00	**.855** (.566-1.29)	**.820** (.510-1.34)	**2.61** (1.76-4.03)	**7.69** (4.41-12.1)	**12.2** (6.94-23.8)	952
	01-02	*	**< LOD**	**2.04** (1.71-2.52)	**4.31** (3.62-5.00)	**6.88** (5.60-9.42)	1187
	03-04	*	**< LOD**	**4.03** (2.81-5.30)	**8.34** (6.69-10.2)	**12.1** (9.31-14.8)	927
Females	99-00	**996** (.620-1.60)	**.960** (.540-1.62)	**2.81** (1.45-5.85)	**8.00** (4.00-13.0)	**12.1** (6.67-19.6)	997
	01-02	*	**.750** (<LOD-1.27)	**2.66** (2.24-3.23)	**6.28** (4.75-7.37)	**9.57** (6.61-13.6)	1332
	03-04	*	**< LOD**	**4.87** (3.82-6.50)	**9.83** (7.54-11.9)	**13.8** (10.5-20.3)	1001
Race/ethnicity							
Mexican Americans	99-00	**.09** (.633-1.89)	**1.05** (.650-1.98)	**3.78** (2.11-6.46)	**9.84** (5.66-15.7)	**15.7** (8.61-29.0)	672
	01-02	*	**.890** (<LOD-1.38)	**2.38** (1.79-3.13)	**5.00** (4.04-6.53)	**7.66** (5.88-10.9)	678
	03-04	*	**.960** (<LOD-2.67)	**4.43** (3.03-6.69)	**9.80** (7.56-13.3)	**16.6** (9.94-22.5)	472
Non-Hispanic blacks	99-00	**.07** (.773-1.47)	**1.18** (.830-1.54)	**2.61** (1.89-3.47)	**5.98** (3.94-9.56)	**11.9** (5.98-22.2)	509
	01-02	*	**.780** (<LOD-1.56)	**2.80** (2.40-3.40)	**7.19** (4.90-8.84)	**9.75** (7.82-14.9)	695
	03-04	*	**.710** (<LOD-1.98)	**4.14** (3.46-5.09)	**7.77** (6.57-10.5)	**11.7** (10.5-13.4)	577
Non-Hispanic whites	99-00	**932** (.549-1.58)	**.900** (.430-1.68)	**2.87** (1.51-5.88)	**8.57** (4.40-14.4)	**13.0** (8.21-23.8)	595
	01-02	*	**< LOD**	**2.30** (1.92-2.74)	**4.95** (3.93-5.93)	**7.80** (6.15-10.7)	948
	03-04	*	**< LOD**	**4.47** (3.37-5.80)	**9.03** (7.53-11.3)	**12.1** (10.1-15.7)	751

< LOD means less than the lim urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethylphosphate (DMP)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.740** (<LOD-1.40)	**2.90** (2.10-4.00)	**7.90** (6.20-8.90)	**14.0** (10.0-19.0)	1949
	01-02	*	**< LOD**	**3.25** (2.77-3.67)	**8.22** (6.95-9.27)	**13.4** (10.9-15.6)	2519
	03-04	*	**< LOD**	**3.99** (3.29-4.96)	**9.17** (7.33-11.9)	**14.8** (12.4-17.8)	1965
Age group							
6-11 years	99-00	**1.58** (1.15-2.18)	**1.10** (.580-2.20)	**4.40** (2.80-6.80)	**10.0** (7.80-21.0)	**22.0** (15.0-33.0)	471
	01-02	*	**.970** (<LOD-2.00)	**5.04** (3.31-7.66)	**12.2** (9.10-15.1)	**18.3** (12.6-41.7)	576
	03-04	*	**< LOD**	**4.53** (3.34-5.96)	**11.0** (5.62-17.9)	**16.2** (7.46-28.3)	310
12-19 years	99-00	*	**.670** (<LOD-1.80)	**3.80** (2.50-4.90)	**9.90** (6.20-18.0)	**22.0** (13.0-29.0)	664
	01-02	*	**.670** (<LOD-1.31)	**4.27** (3.41-5.35)	**9.27** (7.80-12.3)	**14.7** (11.8-21.3)	822
	03-04	*	**1.20** (<LOD-2.27)	**4.61** (3.47-6.72)	**10.9** (7.90-15.0)	**20.9** (12.5-26.8)	717
20-59 years	99-00	*	**.680** (<LOD-1.30)	**2.70** (1.80-3.70)	**6.60** (5.70-8.10)	**9.70** (8.80-14.0)	814
	01-02	*	**< LOD**	**2.95** (2.35-3.41)	**6.95** (5.80-8.82)	**11.5** (9.66-13.7)	1121
	03-04	*	**< LOD**	**3.75** (2.84-4.88)	**8.52** (6.86-10.7)	**14.1** (10.8-17.5)	938
Gender							
Males	99-00	*	**.670** (<LOD-1.30)	**2.90** (2.20-4.00)	**7.90** (6.00-9.30)	**18.0** (10.0-24.0)	952
	01-02	*	**< LOD**	**3.40** (2.49-4.30)	**8.22** (6.67-10.3)	**12.6** (10.9-14.7)	1187
	03-04	*	**< LOD**	**3.89** (2.97-4.89)	**8.14** (6.34-10.4)	**15.1** (10.8-20.4)	946
Females	99-00	*	**.790** (<LOD-1.60)	**2.90** (2.00-4.20)	**7.80** (5.70-9.00)	**11.0** (9.00-18.0)	997
	01-02	*	**< LOD**	**3.06** (2.59-3.67)	**8.34** (6.70-9.64)	**13.7** (10.9-17.2)	1332
	03-04	*	**< LOD**	**4.18** (3.24-5.73)	**10.3** (7.39-13.6)	**14.8** (12.6-19.6)	1019
Race/ethnicity							
Mexican Americans	99-00	*	**1.10** (<LOD-1.80)	**3.80** (2.70-5.30)	**9.60** (6.00-16.0)	**16.0** (8.90-31.0)	672
	01-02	*	**.670** (<LOD-1.51)	**3.24** (2.46-4.27)	**9.28** (7.10-10.7)	**14.4** (10.7-21.0)	678
	03-04	*	**< LOD**	**4.37** (3.15-6.88)	**10.3** (6.92-17.8)	**23.3** (9.61-32.5)	498
Non-Hispanic blacks	99-00	**1.42** (1.16-1.74)	**1.00** (.650-1.50)	**3.60** (2.50-5.50)	**8.90** (6.90-15.0)	**21.0** (14.0-24.0)	509
	01-02	*	**.910** (<LOD-2.29)	**5.45** (3.81-6.78)	**11.5** (8.77-14.9)	**19.4** (14.1-23.3)	695
	03-04	*	**< LOD**	**5.12** (4.11-6.37)	**10.5** (8.31-12.0)	**14.3** (11.7-19.6)	579
Non-Hispanic whites	99-00	*	**< LOD**	**2.90** (1.80-4.20)	**7.90** (5.90-9.00)	**11.0** (9.00-18.0)	595
	01-02	*	**< LOD**	**3.01** (2.34-3.50)	**7.39** (5.98-9.22)	**12.3** (9.63-14.6)	948
	03-04	*	**< LOD**	**3.75** (3.00-4.92)	**8.35** (6.22-12.9)	**14.6** (10.8-20.4)	757

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.58, 0.5, and 0.5, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethylphosphate (DMP) (creatinine corrected)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.810** (<LOD-1.15)	**2.93** (2.11-3.92)	**8.50** (6.96-10.4)	**16.1** (13.3-17.6)	1949
	01-02	*	**< LOD**	**3.00** (2.59-3.33)	**7.83** (6.47-9.04)	**12.7** (10.3-15.0)	2518
	03-04	*	**< LOD**	**3.86** (3.02-4.95)	**9.54** (7.93-10.6)	**14.6** (12.5-17.6)	1962
Age group							
6-11 years	99-00	**1.71** (1.29-2.27)	**1.38** (.890-2.38)	**4.48** (2.88-7.89)	**16.7** (8.21-21.2)	**22.1** (19.2-30.1)	471
	01-02	*	**1.93** (<LOD-2.97)	**5.99** (4.32-8.28)	**12.9** (9.34-18.5)	**20.6** (13.3-34.9)	576
	03-04	*	**< LOD**	**6.87** (3.79-9.00)	**13.9** (9.68-19.4)	**19.6** (13.9-25.9)	310
12-19 years	99-00	*	**.590** (<LOD-.950)	**2.28** (1.70-2.80)	**7.78** (4.16-14.4)	**16.0** (8.70-35.3)	664
	01-02	*	**.910** (<LOD-1.27)	**3.29** (2.75-3.78)	**6.29** (5.51-7.30)	**9.83** (7.94-14.2)	821
	03-04	*	**1.00** (<LOD-1.68)	**4.16** (3.37-5.07)	**8.81** (7.78-10.2)	**12.7** (10.3-17.7)	715
20-59 years	99-00	*	**.760** (<LOD-1.12)	**2.88** (1.89-3.99)	**8.11** (5.89-10.3)	**14.6** (10.4-16.8)	814
	01-02	*	**< LOD**	**2.55** (2.05-3.03)	**6.92** (5.85-8.00)	**11.5** (9.38-13.6)	1121
	03-04	*	**< LOD**	**3.77** (2.72-4.55)	**8.78** (6.68-10.5)	**13.5** (11.2-15.6)	937
Gender							
Males	99-00	*	**.620** (<LOD-.940)	**2.38** (1.86-3.18)	**7.58** (4.64-11.6)	**15.2** (9.74-19.5)	952
	01-02	*	**< LOD**	**2.61** (2.07-3.07)	**6.25** (4.82-8.42)	**10.5** (8.28-12.7)	1187
	03-04	*	**< LOD**	**2.95** (2.23-3.91)	**7.93** (6.33-10.4)	**12.5** (10.4-15.4)	945
Females	99-00	*	**1.00** (<LOD-1.71)	**3.63** (2.30-5.19)	**9.12** (7.82-11.7)	**16.4** (11.7-19.7)	997
	01-02	*	**< LOD**	**3.43** (2.74-4.27)	**9.00** (7.51-10.1)	**15.0** (11.9-17.8)	1331
	03-04	*	**< LOD**	**5.00** (3.79-6.30)	**10.1** (8.27-13.4)	**16.0** (13.0-19.6)	1017
Race/ethnicity							
Mexican Americans	99-00	*	**1.06** (<LOD-1.55)	**3.89** (2.54-5.45)	**9.41** (7.69-11.5)	**16.7** (11.7-23.6)	672
	01-02	*	**.920** (<LOD-1.27)	**3.03** (2.52-3.72)	**8.03** (6.09-11.3)	**14.6** (11.4-16.2)	678
	03-04	*	**< LOD**	**4.14** (2.44-6.30)	**12.3** (7.39-17.6)	**19.5** (15.3-21.8)	497
Non-Hispanic blacks	99-00	**.973** (.780-1.21)	**.690** (.530-1.06)	**2.67** (1.89-3.77)	**7.07** (5.09-11.4)	**14.0** (10.6-19.1)	509
	01-02	*	**.850** (<LOD-1.34)	**3.36** (2.68-4.29)	**7.63** (6.25-9.45)	**13.2** (9.50-17.2)	694
	03-04	*	**< LOD**	**3.38** (2.75-3.95)	**6.94** (5.53-8.42)	**10.8** (8.42-19.2)	578
Non-Hispanic whites	99-00	*	**< LOD**	**3.15** (1.97-4.32)	**8.73** (5.89-13.3)	**15.8** (10.0-21.2)	595
	01-02	*	**< LOD**	**2.77** (2.20-3.37)	**8.00** (5.91-9.86)	**12.9** (9.85-17.7)	948
	03-04	*	**< LOD**	**3.89** (3.01-5.54)	**9.67** (7.96-11.2)	**14.6** (11.4-18.2)	756

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Diethylthiophosphate (DETP)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.500** (<LOD-.690)	**.760** (.620-1.10)	**1.40** (1.10-1.80)	**2.20** (1.70-2.80)	1949
	01-02	**.457** (.353-.592)	**.570** (.390-.880)	**1.50** (1.25-1.79)	**2.48** (2.22-3.04)	**3.94** (3.17-4.95)	2519
	03-04	*	**< LOD**	**.830** (.690-.950)	**1.77** (1.42-2.31)	**2.80** (2.31-3.78)	1905
Age group							
6-11 years	99-00	*	**.600** (<LOD-.810)	**.910** (.720-1.30)	**1.70** (1.20-3.20)	**3.20** (1.70-7.30)	471
	01-02	**.453** (.350-.585)	**.550** (.350-.850)	**1.58** (1.33-2.04)	**2.75** (2.22-3.38)	**4.08** (2.95-5.16)	575
	03-04	*	**< LOD**	**.820** (.580-.970)	**1.45** (1.05-2.16)	**2.18** (1.45-4.13)	296
12-19 years	99-00	*	**.210** (<LOD-.710)	**.780** (.600-1.20)	**1.50** (1.20-2.30)	**2.30** (1.60-4.30)	664
	01-02	**.505** (.388-.657)	**.690** (.440-.960)	**1.61** (1.32-1.94)	**2.57** (2.23-3.39)	**4.08** (2.73-5.86)	822
	03-04	*	**.260** (<LOD-.400)	**.930** (.750-1.13)	**2.14** (1.75-2.89)	**3.27** (2.69-4.83)	690
20-59 years	99-00	*	**.490** (<LOD-.670)	**.740** (.600-.930)	**1.30** (.990-1.80)	**2.00** (1.50-2.60)	814
	01-02	**.449** (.340-.592)	**.540** (.380-.880)	**1.45** (1.19-1.79)	**2.46** (2.11-3.17)	**3.83** (2.96-5.34)	1122
	03-04	*	**< LOD**	**.800** (.650-.960)	**1.76** (1.37-2.32)	**2.65** (2.31-3.89)	919
Gender							
Males	99-00	*	**.510** (<LOD-.700)	**.790** (.680-1.10)	**1.50** (1.20-2.20)	**2.70** (1.90-4.10)	952
	01-02	**.459** (.359-.587)	**.570** (.390-.860)	**1.50** (1.30-1.78)	**2.54** (2.16-3.34)	**3.83** (2.76-6.15)	1187
	03-04	*	**< LOD**	**.880** (.720-1.01)	**2.20** (1.54-2.50)	**2.95** (2.36-4.29)	907
Females	99-00	*	**< LOD**	**.720** (.570-1.00)	**1.30** (.910-1.60)	**1.70** (1.30-3.20)	997
	01-02	**.455** (.336-.618)	**.550** (.380-.940)	**1.48** (1.14-1.89)	**2.45** (2.11-3.35)	**3.94** (2.68-5.49)	1332
	03-04	*	**< LOD**	**.780** (.590-.970)	**1.47** (1.22-2.00)	**2.57** (1.87-3.78)	998
Race/ethnicity							
Mexican Americans	99-00	*	**.570** (<LOD-.780)	**.840** (.740-.980)	**1.50** (1.20-1.90)	**2.20** (2.00-2.90)	672
	01-02	**.549** (.398-.759)	**.710** (.460-.960)	**1.40** (1.01-1.98)	**2.63** (1.98-3.47)	**3.98** (2.74-5.21)	678
	03-04	*	**.240** (<LOD-.380)	**.960** (.680-1.54)	**2.22** (1.46-3.83)	**3.97** (2.22-8.80)	478
Non-Hispanic blacks	99-00	**.343** (.201-.584)	**.570** (<LOD-.750)	**.820** (.690-1.20)	**1.80** (1.30-3.20)	**3.60** (2.00-4.80)	509
	01-02	**.749** (.592-.949)	**1.18** (.740-1.49)	**1.86** (1.77-2.03)	**3.55** (3.01-3.91)	**5.27** (3.89-6.74)	695
	03-04	**.467** (.382-.570)	**.450** (<LOD-.730)	**1.09** (.930-1.26)	**2.32** (1.59-2.88)	**3.26** (2.41-5.46)	553
Non-Hispanic whites	99-00	*	**.160** (<LOD-.700)	**.740** (.580-1.10)	**1.30** (.960-1.90)	**1.90** (1.50-2.80)	595
	01-02	**.425** (.303-.597)	**.510** (.280-.930)	**1.46** (1.10-1.83)	**2.41** (2.05-3.17)	**3.73** (2.59-6.15)	948
	03-04	*	**< LOD**	**.710** (.560-.910)	**1.73** (1.29-2.31)	**2.64** (1.96-3.89)	745

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.09, 0.1, and 0.2, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Diethylthiophosphate (DETP) (creatinine corrected)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.250** (<LOD-.480)	**.710** (.460-1.07)	**1.72** (1.17-2.32)	**2.64** (2.08-3.06)	1949
	01-02	**.453** (.348-.590)	**.520** (.330-.760)	**1.33** (1.04-1.66)	**2.84** (2.22-3.76)	**4.61** (3.42-6.65)	2518
	03-04	*	**< LOD**	**.700** (.580-.830)	**1.47** (1.16-2.04)	**2.62** (2.00-3.72)	1903
Age group							
6-11 years	99-00	*	**.470** (<LOD-.870)	**1.08** (.800-1.32)	**1.75** (1.44-2.36)	**2.45** (2.04-5.32)	471
	01-02	**.591** (.471-.742)	**.640** (.400-1.05)	**1.63** (1.31-1.94)	**3.22** (2.72-4.16)	**5.70** (3.84-6.80)	575
	03-04	*	**< LOD**	**.870** (.590-1.09)	**1.57** (1.08-2.67)	**2.67** (1.57-4.05)	296
12-19 years	99-00	*	**.180** (<LOD-.400)	**.510** (.320-.820)	**1.07** (.720-1.61)	**1.97** (1.07-3.92)	664
	01-02	**.393** (.300-.515)	**.530** (.310-.740)	**1.23** (.980-1.53)	**2.19** (1.61-3.07)	**3.14** (2.25-3.97)	821
	03-04	*	**.300** (<LOD-.350)	**.640** (.560-.730)	**1.49** (1.16-1.60)	**1.97** (1.57-2.43)	689
20-59 years	99-00	*	**.250** (<LOD-.460)	**.680** (.440-1.08)	**1.79** (1.08-2.39)	**2.75** (2.02-3.22)	814
	01-02	**.447** (.335-.597)	**.490** (.320-.740)	**1.32** (.990-1.71)	**2.87** (2.08-3.95)	**4.69** (3.20-7.81)	1122
	03-04	*	**< LOD**	**.700** (.550-.880)	**1.47** (1.11-2.23)	**2.82** (2.02-3.80)	918
Gender							
Males	99-00	*	**.270** (<LOD-.470)	**.670** (.520-.840)	**1.34** (1.08-2.17)	**2.67** (1.67-3.23)	952
	01-02	**.372** (.285-.485)	**.460** (.270-.690)	**1.11** (.940-1.33)	**2.05** (1.55-3.11)	**3.38** (2.47-4.71)	1187
	03-04	*	**< LOD**	**.590** (.500-.760)	**1.42** (.950-2.07)	**2.62** (1.61-3.97)	906
Females	99-00	*	**< LOD**	**.790** (.380-1.50)	**1.89** (1.07-2.52)	**2.52** (1.89-3.75)	997
	01-02	**.552** (.412-.739)	**.580** (.370-.910)	**1.60** (1.18-2.42)	**3.70** (2.77-4.99)	**6.57** (3.92-8.82)	1331
	03-04	*	**< LOD**	**.750** (.660-.900)	**1.50** (1.22-2.23)	**2.60** (2.08-3.98)	997
Race/ethnicity							
Mexican Americans	99-00	*	**.330** (<LOD-.790)	**.830** (.550-1.20)	**1.69** (1.20-2.43)	**2.71** (1.75-3.78)	672
	01-02	**.509** (.377-.688)	**.560** (.380-.840)	**1.28** (1.03-1.67)	**2.55** (1.77-3.72)	**3.72** (2.58-6.30)	678
	03-04	*	**.310** (<LOD-.390)	**.750** (.480-1.22)	**1.92** (1.22-3.43)	**3.66** (2.02-6.17)	478
Non-Hispanic blacks	99-00	**.234** (.136-.403)	**.310** (<LOD-.580)	**.720** (.510-.850)	**1.39** (1.03-2.10)	**2.91** (1.49-4.24)	509
	01-02	**.535** (.444-.645)	**.710** (.550-.920)	**1.43** (1.32-1.60)	**2.73** (2.30-2.98)	**4.00** (3.05-4.99)	694
	03-04	**.305** (.253-.368)	**.280** (<LOD-.380)	**.640** (.540-.820)	**1.41** (.930-1.79)	**2.13** (1.38-3.90)	552
Non-Hispanic whites	99-00	*	**.230** (<LOD-.550)	**.710** (.390-1.22)	**1.88** (1.05-2.58)	**2.64** (2.08-3.07)	595
	01-02	**.448** (.318-.630)	**.510** (.270-.800)	**1.38** (1.00-1.88)	**3.08** (2.29-4.23)	**5.77** (3.42-8.44)	948
	03-04	*	**< LOD**	**.700** (.560-.840)	**1.45** (1.06-2.08)	**2.58** (1.73-3.97)	744

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethylthiophosphate (DMTP)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.82** (1.36-2.44)	**2.70** (1.40-4.10)	**11.0** (8.40-16.0)	**38.0** (25.0-41.0)	**48.0** (38.0-62.0)	1948
	01-02	*	**.470** (<LOD-1.41)	**4.02** (2.92-5.70)	**16.2** (12.4-22.9)	**32.6** (26.6-45.3)	2518
	03-04	**2.10** (1.83-2.40)	**1.90** (1.61-2.26)	**5.65** (4.63-6.80)	**17.3** (14.5-20.1)	**31.1** (26.5-40.0)	1965
Age group							
6-11 years	99-00	**2.72** (1.93-3.85)	**4.20** (2.50-7.20)	**20.0** (13.0-29.0)	**40.0** (38.0-52.0)	**62.0** (40.0-92.0)	471
	01-02	*	**1.46** (.600-2.69)	**8.33** (5.75-14.0)	**28.4** (19.7-41.4)	**45.7** (28.5-74.5)	575
	03-04	**2.79** (2.25-3.45)	**2.67** (1.81-3.88)	**6.95** (5.64-8.58)	**19.4** (10.5-27.4)	**30.9** (19.4-76.5)	310
12-19 years	99-00	**2.53** (1.64-3.92)	**3.70** (1.70-6.80)	**16.0** (11.0-31.0)	**38.0** (33.0-58.0)	**69.0** (38.0-260)	664
	01-02	*	**1.04** (<LOD-2.12)	**4.83** (3.35-6.48)	**20.8** (12.2-27.9)	**34.9** (23.6-54.7)	822
	03-04	**2.21** (1.81-2.70)	**1.83** (1.46-2.16)	**5.91** (4.04-8.78)	**18.7** (12.2-33.9)	**47.1** (22.2-80.8)	717
20-59 years	99-00	**1.59** (1.17-2.16)	**2.30** (.830-3.80)	**9.10** (7.10-13.0)	**38.0** (19.0-39.0)	**39.0** (38.0-58.0)	813
	01-02	*	**< LOD**	**3.32** (2.29-4.96)	**13.6** (9.50-20.0)	**30.0** (20.5-45.3)	1121
	03-04	**1.98** (1.71-2.30)	**1.78** (1.48-2.18)	**5.11** (4.31-6.53)	**16.7** (12.1-20.8)	**28.5** (24.1-40.0)	938
Gender							
Males	99-00	**2.10** (1.48-2.98)	**3.50** (2.20-4.80)	**14.0** (8.00-24.0)	**38.0** (21.0-49.0)	**42.0** (38.0-53.0)	952
	01-02	*	**.610** (<LOD-1.42)	**4.21** (3.07-5.97)	**18.3** (12.2-27.2)	**31.1** (25.0-43.3)	1187
	03-04	**2.13** (1.80-2.53)	**1.94** (1.49-2.44)	**6.09** (4.44-7.23)	**16.1** (10.9-21.1)	**26.8** (22.0-41.6)	946
Females	99-00	**1.59** (1.23-2.06)	**2.00** (.690-3.60)	**9.70** (7.30-14.0)	**38.0** (26.0-39.0)	**52.0** (38.0-110)	996
	01-02	*	**< LOD**	**3.76** (2.50-5.71)	**15.9** (10.6-22.0)	**34.3** (23.2-47.3)	1331
	03-04	**2.06** (1.74-2.44)	**1.86** (1.58-2.18)	**5.21** (4.27-6.77)	**19.8** (12.8-24.0)	**33.8** (26.1-47.8)	1019
Race/ethnicity							
Mexican Americans	99-00	**1.79** (1.05-3.05)	**2.00** (.530-4.40)	**11.0** (6.70-17.0)	**39.0** (32.0-62.0)	**140** (46.0-230)	671
	01-02	*	**< LOD**	**3.76** (2.66-5.18)	**15.1** (11.1-19.1)	**35.2** (19.1-46.0)	678
	03-04	**2.41** (1.86-3.11)	**2.54** (1.41-4.04)	**6.52** (4.90-8.13)	**18.6** (11.7-22.3)	**28.9** (19.2-39.8)	498
Non-Hispanic blacks	99-00	**2.13** (1.57-2.88)	**3.60** (2.10-4.70)	**12.0** (8.80-18.0)	**38.0** (20.0-41.0)	**41.0** (37.0-110)	509
	01-02	**1.61** (1.19-2.19)	**1.26** (.660-2.05)	**5.54** (3.29-9.41)	**20.6** (15.6-27.7)	**42.9** (27.2-62.8)	695
	03-04	**2.10** (1.83-2.41)	**1.85** (1.50-2.29)	**5.12** (3.87-7.90)	**20.4** (15.2-26.1)	**32.0** (24.9-51.9)	579
Non-Hispanic whites	99-00	**1.77** (1.23-2.53)	**2.70** (.830-4.40)	**11.0** (7.50-17.0)	**38.0** (17.0-53.0)	**48.0** (38.0-69.0)	595
	01-02	*	**< LOD**	**3.99** (2.46-6.14)	**17.3** (10.1-25.0)	**33.1** (25.0-50.2)	947
	03-04	**2.10** (1.79-2.45)	**1.90** (1.57-2.30)	**5.71** (4.43-7.10)	**17.3** (12.8-21.1)	**31.3** (24.0-47.8)	757

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.18, 0.4, and 0.5, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethylthiophosphate (DMTP) (creatinine corrected)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.64** (1.22-2.20)	**2.12** (1.22-3.35)	**9.57** (6.59-15.8)	**32.0** (23.9-41.1)	**51.0** (39.0-70.1)	1948
	01-02	*	**.860** (<LOD-1.33)	**3.79** (2.50-5.19)	**13.3** (10.9-18.8)	**27.2** (21.7-37.7)	2517
	03-04	**1.97** (1.71-2.27)	**1.75** (1.54-2.06)	**5.21** (4.46-5.95)	**15.7** (11.7-19.7)	**30.4** (25.4-34.2)	1962
Age group							
6-11 years	99-00	**2.95** (2.25-3.86)	**5.32** (3.75-6.33)	**19.1** (12.2-28.0)	**47.0** (32.1-60.3)	**66.1** (50.9-95.0)	471
	01-02	*	**2.16** (1.32-3.12)	**10.6** (7.84-13.6)	**28.7** (18.8-45.0)	**48.1** (33.4-71.1)	575
	03-04	**3.40** (2.70-4.28)	**3.41** (2.40-4.17)	**7.91** (6.43-12.2)	**25.2** (16.8-34.2)	**36.1** (25.4-67.7)	310
12-19 years	99-00	**1.71** (1.07-2.75)	**2.14** (.890-4.83)	**13.5** (6.46-22.6)	**36.0** (25.6-51.4)	**61.5** (41.7-109)	664
	01-02	*	**.930** (<LOD-1.56)	**3.56** (2.38-5.57)	**12.2** (8.96-16.0)	**22.5** (13.2-34.7)	821
	03-04	**1.66** (1.37-2.03)	**1.52** (1.18-1.82)	**4.38** (3.29-5.66)	**13.3** (9.94-20.5)	**26.5** (15.5-36.0)	715
20-59 years	99-00	**1.47** (1.07-2.02)	**1.90** (.870-3.11)	**8.09** (5.19-14.6)	**27.0** (19.8-37.6)	**47.5** (34.2-70.1)	813
	01-02	*	**< LOD**	**3.16** (1.99-4.62)	**11.9** (7.79-17.2)	**25.2** (15.9-37.0)	1121
	03-04	**1.88** (1.61-2.19)	**1.67** (1.45-1.94)	**4.88** (4.20-5.68)	**13.9** (10.3-19.7)	**30.4** (19.7-38.2)	937
Gender							
Males	99-00	**1.61** (1.11-2.34)	**2.39** (1.27-3.51)	**9.27** (6.00-16.9)	**28.9** (19.0-40.4)	**41.1** (34.9-52.9)	952
	01-02	*	**.750** (<LOD-1.08)	**3.35** (2.26-4.60)	**12.5** (8.54-15.9)	**24.0** (14.6-38.9)	1187
	03-04	**1.70** (1.43-2.02)	**1.67** (1.38-1.96)	**4.47** (3.63-5.36)	**12.3** (8.47-17.7)	**24.5** (17.6-32.5)	945
Females	99-00	**1.66** (1.26-2.18)	**2.01** (.870-3.33)	**10.0** (6.67-16.2)	**34.9** (26.2-47.1)	**70.1** (39.0-118)	996
	01-02	*	**< LOD**	**4.22** (2.40-7.00)	**15.6** (11.3-22.6)	**29.6** (24.8-43.8)	1330
	03-04	**2.28** (1.91-2.72)	**1.88** (1.59-2.44)	**6.00** (4.80-8.30)	**19.4** (12.8-26.2)	**32.6** (27.3-42.0)	1017
Race/ethnicity							
Mexican Americans	99-00	**1.60** (.899-2.86)	**1.83** (.680-4.23)	**10.4** (5.95-16.9)	**37.0** (23.1-63.1)	**112** (40.5-190)	671
	01-02	*	**< LOD**	**3.55** (2.52-4.93)	**13.2** (9.61-22.7)	**30.2** (22.7-47.7)	678
	03-04	**2.16** (1.58-2.94)	**2.24** (1.67-3.00)	**5.88** (4.14-8.71)	**15.7** (10.7-20.1)	**23.7** (18.9-36.9)	497
Non-Hispanic blacks	99-00	**1.45** (1.03-2.06)	**1.75** (1.17-3.06)	**8.48** (4.36-13.4)	**25.5** (15.4-39.3)	**54.4** (25.5-97.6)	509
	01-02	**1.15** (.888-1.48)	**1.02** (.670-1.35)	**3.62** (2.33-5.18)	**13.4** (9.69-18.8)	**23.0** (17.5-43.8)	694
	03-04	**1.37** (1.23-1.53)	**1.19** (1.06-1.31)	**3.50** (2.69-5.07)	**11.8** (7.95-16.2)	**23.9** (13.3-27.1)	578
Non-Hispanic whites	99-00	**1.68** (1.16-2.43)	**2.22** (.870-3.51)	**9.40** (5.58-17.0)	**33.3** (20.6-49.4)	**52.9** (39.0-71.1)	595
	01-02	*	**< LOD**	**3.82** (2.19-6.38)	**14.3** (10.1-22.1)	**27.4** (21.7-43.8)	947
	03-04	**2.08** (1.76-2.46)	**1.80** (1.59-2.27)	**5.36** (4.46-6.23)	**17.4** (11.4-21.6)	**31.7** (24.2-38.2)	756

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Diethyldithiophosphate (DEDTP)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.090** (<LOD-.140)	**.210** (.140-.290)	**.470** (.380-.640)	**.870** (.640-1.10)	1949
	01-02	*	**< LOD**	**< LOD**	**.610** (.410-.770)	**.850** (.700-1.30)	2516
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.320** (.170-.540)	1965
Age group							
6-11 years	99-00	*	**.090** (<LOD-.160)	**.190** (.130-.280)	**.430** (.300-.650)	**.850** (.470-1.00)	471
	01-02	*	**< LOD**	**< LOD**	**.630** (.380-.870)	**.940** (.690-1.42)	576
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.540** (<LOD-.650)	310
12-19 years	99-00	*	**.080** (<LOD-.180)	**.260** (.120-.350)	**.640** (.420-.840)	**.930** (.720-1.30)	664
	01-02	*	**< LOD**	**< LOD**	**.560** (.330-.730)	**.820** (.610-.990)	822
	03-04	*	**< LOD**	**< LOD**	**.150** (<LOD-.350)	**.450** (.370-.570)	717
20-59 years	99-00	*	**.090** (<LOD-.130)	**.210** (.130-.290)	**.450** (.360-.640)	**.900** (.610-1.10)	814
	01-02	*	**< LOD**	**< LOD**	**.620** (.430-.760)	**.830** (.700-1.32)	1118
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.220** (<LOD-.580)	938
Gender							
Males	99-00	*	**.090** (<LOD-.150)	**.220** (.140-.310)	**.490** (.380-.680)	**.870** (.680-1.10)	952
	01-02	*	**< LOD**	**< LOD**	**.600** (.370-.740)	**.770** (.680-1.03)	1187
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.390** (.130-.540)	946
Females	99-00	*	**.090** (<LOD-.130)	**.190** (.110-.310)	**.460** (.320-.840)	**.870** (.440-1.40)	997
	01-02	*	**< LOD**	**< LOD**	**.660** (.460-.850)	**.990** (.700-1.42)	1329
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.240** (<LOD-.700)	1019
Race/ethnicity							
Mexican Americans	99-00	**.130** (.099-.171)	**.100** (.050-.200)	**.310** (.230-.390)	**.650** (.530-.860)	**1.10** (.860-1.60)	672
	01-02	*	**< LOD**	**< LOD**	**.720** (.410-1.13)	**1.12** (.700-1.58)	678
	03-04	*	**< LOD**	**< LOD**	**.120** (<LOD-.550)	**.680** (.300-1.15)	498
Non-Hispanic blacks	99-00	**.117** (.084-.162)	**.090** (<LOD-.230)	**.270** (.140-.410)	**.560** (.400-.830)	**.870** (.650-1.20)	509
	01-02	*	**< LOD**	**< LOD**	**.630** (.410-.830)	**.820** (.730-.990)	694
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.310** (.160-.540)	579
Non-Hispanic whites	99-00	*	**.080** (<LOD-.160)	**.190** (.120-.290)	**.450** (.310-.720)	**.870** (.510-1.30)	595
	01-02	*	**< LOD**	**< LOD**	**.610** (.360-.780)	**.830** (.650-1.36)	947
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.290** (<LOD-.540)	757

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.05, 0.1, and 0.1, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Diethyldithiophosphate (DEDTP) (creatinine corrected)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**.070** (<LOD-.110)	**.200** (.140-.290)	**.550** (.390-.700)	**.860** (.670-1.14)	1949
	01-02	*	**< LOD**	**< LOD**	**.580** (.390-.750)	**1.01** (.710-1.43)	2515
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.410** (.330-.510)	1962
Age group							
6-11 years	99-00	*	**.100** (<LOD-.140)	**.190** (.150-.270)	**.570** (.410-.760)	**1.03** (.570-1.58)	471
	01-02	*	**< LOD**	**< LOD**	**.780** (.610-1.12)	**1.36** (1.02-1.86)	576
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.470** (<LOD-.970)	310
12-19 years	99-00	*	**.050** (<LOD-.080)	**.170** (.100-.220)	**.440** (.230-.730)	**.730** (.380-1.09)	664
	01-02	*	**< LOD**	**< LOD**	**.360** (.250-.540)	**.670** (.380-.990)	821
	03-04	*	**< LOD**	**< LOD**	**.230** (<LOD-.260)	**.330** (.240-.600)	715
20-59 years	99-00	*	**.080** (<LOD-.110)	**.210** (.140-.310)	**.550** (.360-.730)	**.860** (.650-1.20)	814
	01-02	*	**< LOD**	**< LOD**	**.580** (.380-.740)	**1.03** (.700-1.60)	1118
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.400** (<LOD-.540)	937
Gender							
Males	99-00	*	**.070** (<LOD-.110)	**.190** (.140-.230)	**.410** (.340-.500)	**.720** (.520-.940)	952
	01-02	*	**< LOD**	**< LOD**	**.380** (.300-.650)	**.740** (.580-1.03)	1187
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.330** (.260-.410)	945
Females	99-00	*	**.090** (<LOD-.120)	**.220** (.140-.360)	**.670** (.410-.870)	**.890** (.660-1.62)	997
	01-02	*	**< LOD**	**< LOD**	**.700** (.490-1.00)	**1.24** (.800-1.86)	1328
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.500** (<LOD-.640)	1017
Race/ethnicity							
Mexican Americans	99-00	**.116** (.084-.161)	**.090** (.060-.170)	**.300** (.190-.410)	**.810** (.570-.990)	**1.19** (.860-2.66)	672
	01-02	*	**< LOD**	**< LOD**	**.850** (.440-1.24)	**1.29** (.880-1.78)	678
	03-04	*	**< LOD**	**< LOD**	**.320** (<LOD-.450)	**.540** (.330-.940)	497
Non-Hispanic blacks	99-00	**.080** (.057-.111)	**.070** (<LOD-.110)	**.170** (.110-.280)	**.450** (.300-.580)	**.700** (.500-1.02)	509
	01-02	*	**< LOD**	**< LOD**	**.460** (.330-.580)	**.720** (.510-.960)	693
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.270** (.180-.400)	578
Non-Hispanic whites	99-00	*	**.070** (<LOD-.120)	**.200** (.140-.310)	**.560** (.380-.730)	**.880** (.600-1.38)	595
	01-02	*	**< LOD**	**< LOD**	**.540** (.360-.780)	**1.03** (.640-1.67)	947
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.370** (<LOD-.520)	756

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethyldithiophosphate (DMDTP)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**2.30** (1.30-3.90)	**13.0** (5.00-17.0)	**19.0** (17.0-38.0)	1949
	01-02	*	**< LOD**	**.890** (.210-1.30)	**2.49** (1.88-3.40)	**5.10** (3.55-8.35)	2518
	03-04	*	**< LOD**	**.640** (.480-.800)	**1.99** (1.38-3.30)	**5.05** (3.30-7.16)	1930
Age group							
6-11 years	99-00	**.691** (.425-1.12)	**.740** (.080-1.80)	**4.30** (2.40-8.60)	**17.0** (6.90-37.0)	**32.0** (17.0-44.0)	471
	01-02	*	**< LOD**	**1.30** (.750-2.11)	**3.53** (2.20-4.50)	**7.33** (4.32-9.74)	575
	03-04	*	**< LOD**	**.900** (.620-1.14)	**2.94** (1.14-5.48)	**5.48** (2.94-8.53)	306
12-19 years	99-00	*	**< LOD**	**2.30** (1.40-4.50)	**13.0** (5.40-20.0)	**20.0** (17.0-38.0)	664
	01-02	*	**< LOD**	**.830** (.400-1.14)	**2.52** (1.85-3.07)	**4.63** (3.59-5.83)	821
	03-04	*	**< LOD**	**.580** (.350-.770)	**1.46** (1.12-1.99)	**2.67** (1.82-4.49)	699
20-59 years	99-00	*	**< LOD**	**2.10** (.840-3.60)	**11.0** (4.00-17.0)	**17.0** (7.70-50.0)	814
	01-02	*	**< LOD**	**.840** (<LOD-1.31)	**2.32** (1.70-3.40)	**4.90** (2.90-9.52)	1122
	03-04	*	**< LOD**	**.610** (.350-.800)	**2.00** (1.36-3.63)	**5.07** (3.62-8.62)	925
Gender							
Males	99-00	*	**.110** (<LOD-.610)	**2.30** (1.20-4.90)	**16.0** (5.70-17.0)	**19.0** (17.0-38.0)	952
	01-02	*	**< LOD**	**.840** (.190-1.28)	**2.40** (1.83-3.28)	**5.13** (3.53-7.86)	1187
	03-04	*	**< LOD**	**.600** (.260-.910)	**1.76** (1.07-3.35)	**4.45** (2.24-7.97)	935
Females	99-00	*	**< LOD**	**2.20** (1.10-3.90)	**11.0** (4.20-17.0)	**20.0** (13.0-40.0)	997
	01-02	*	**< LOD**	**.960** (.170-1.39)	**2.52** (1.94-3.68)	**5.10** (3.31-10.6)	1331
	03-04	*	**< LOD**	**.690** (.510-.850)	**2.40** (1.43-4.15)	**5.07** (3.35-10.3)	995
Race/ethnicity							
Mexican Americans	99-00	*	**.250** (<LOD-.870)	**1.90** (1.10-3.00)	**5.80** (4.10-9.70)	**12.0** (5.90-28.0)	672
	01-02	*	**< LOD**	**1.03** (.750-1.37)	**2.67** (2.07-3.42)	**4.47** (3.70-7.01)	678
	03-04	*	**< LOD**	**.730** (.360-1.21)	**2.07** (1.36-3.15)	**5.26** (2.30-6.99)	498
Non-Hispanic blacks	99-00	*	**.330** (<LOD-1.20)	**3.20** (1.40-7.00)	**14.0** (5.70-30.0)	**19.0** (17.0-39.0)	509
	01-02	*	**< LOD**	**.770** (<LOD-1.67)	**2.11** (1.55-4.18)	**4.39** (2.51-8.66)	695
	03-04	*	**< LOD**	**.590** (.370-.720)	**1.61** (1.05-3.11)	**4.51** (2.23-6.97)	552
Non-Hispanic whites	99-00	*	**< LOD**	**2.00** (.800-4.00)	**13.0** (3.90-20.0)	**20.0** (16.0-40.0)	595
	01-02	*	**< LOD**	**.960** (<LOD-1.42)	**2.49** (1.83-3.65)	**5.74** (3.28-9.87)	947
	03-04	*	**< LOD**	**.640** (.380-.880)	**1.96** (1.21-3.87)	**5.05** (2.29-10.6)	752

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.08, 0.1, and 0.1, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethyldithiophosphate (DMDTP) (creatinine corrected)

Metabolite of Several Organophosphorus Insecticides

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**1.88** (.970-3.86)	**10.1** (5.31-18.3)	**21.7** (12.8-33.7)	1949
	01-02	*	< LOD	**.670** (.330-1.08)	**2.60** (1.85-3.69)	**5.83** (4.23-7.75)	2517
	03-04	*	< LOD	**.500** (.340-.650)	**2.14** (1.21-3.18)	**5.27** (2.69-7.61)	1927
Age group							
6-11 years	99-00	**.748** (.474-1.18)	**.790** (.190-1.60)	**4.07** (2.31-7.18)	**16.2** (8.22-27.0)	**30.8** (20.2-38.9)	471
	01-02	*	< LOD	**1.36** (.800-2.31)	**4.10** (2.67-6.24)	**6.98** (4.40-12.8)	575
	03-04	*	< LOD	**.960** (.580-1.57)	**3.38** (2.28-6.15)	**7.12** (4.48-7.55)	306
12-19 years	99-00	*	< LOD	**1.52** (.620-3.47)	**9.48** (4.04-16.8)	**21.5** (9.48-42.3)	664
	01-02	*	< LOD	**.540** (.310-.770)	**2.02** (1.49-2.40)	**3.13** (2.51-4.67)	820
	03-04	*	< LOD	**.360** (.240-.580)	**1.02** (.630-1.57)	**2.45** (1.33-3.39)	697
20-59 years	99-00	*	< LOD	**1.71** (.850-3.56)	**8.50** (4.00-19.1)	**20.5** (8.57-40.7)	814
	01-02	*	< LOD	**.600** (<LOD-1.05)	**2.56** (1.64-4.03)	**6.33** (3.96-8.17)	1122
	03-04	*	< LOD	**.450** (.340-.580)	**2.17** (1.10-3.64)	**5.71** (2.47-10.1)	924
Gender							
Males	99-00	*	**.150** (<LOD-.370)	**1.79** (.840-3.97)	**11.0** (4.62-17.4)	**18.1** (7.51-44.7)	952
	01-02	*	< LOD	**.580** (.270-.820)	**2.01** (1.40-2.67)	**4.67** (2.90-6.80)	1187
	03-04	*	< LOD	**.370** (.260-.590)	**1.57** (.730-3.32)	**3.74** (2.14-6.53)	934
Females	99-00	*	< LOD	**2.06** (.940-4.00)	**9.30** (4.96-25.5)	**27.0** (9.66-47.5)	997
	01-02	*	< LOD	**.820** (.370-1.43)	**2.92** (2.29-4.56)	**7.73** (4.44-11.9)	1330
	03-04	*	< LOD	**.560** (.390-.790)	**2.62** (1.33-4.41)	**5.88** (2.82-11.6)	993
Race/ethnicity							
Mexican Americans	99-00	*	**.270** (<LOD-.660)	**1.35** (.860-2.53)	**6.55** (3.83-11.8)	**16.7** (6.25-38.8)	672
	01-02	*	< LOD	**.830** (.540-1.11)	**2.59** (1.88-3.22)	**4.86** (3.32-6.37)	678
	03-04	*	< LOD	**.650** (.320-1.10)	**2.04** (1.09-3.84)	**4.50** (2.11-5.88)	497
Non-Hispanic blacks	99-00	*	**.250** (<LOD-.700)	**2.40** (.690-5.44)	**9.41** (4.81-17.8)	**17.9** (11.5-40.7)	509
	01-02	*	< LOD	**.430** (<LOD-.930)	**1.80** (.830-3.50)	**3.65** (2.33-5.91)	694
	03-04	*	< LOD	**.340** (.260-.430)	**.890** (.740-1.50)	**2.33** (1.12-4.55)	551
Non-Hispanic whites	99-00	*	< LOD	**1.77** (.780-4.02)	**11.4** (4.07-21.5)	**21.5** (11.4-34.8)	595
	01-02	*	< LOD	**.710** (<LOD-1.31)	**2.85** (1.91-4.96)	**7.29** (4.25-9.47)	947
	03-04	*	< LOD	**.470** (.340-.700)	**2.25** (1.02-4.03)	**5.89** (2.47-10.1)	751

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Organophosphorus Insecticides: Specific Metabolites

General Information

The specific metabolites of the organophosphorus insecticides discussed in this section are those that are often measured in biomonitoring studies. These metabolites differ from the dialkyl phosphate metabolites because each specific metabolite derives from one or only a few parent insecticides. The table below shows the parent organophosphorus insecticides and their metabolites measured in this *Report*. For example, malathion is metabolized to malathion dicarboxylic acid; parathion and methyl parathion are metabolized to para-nitrophenol. In addition to reflecting exposure to the parent insecticide, the level may reflect exposure to the environmental degradation products of these pesticides. For general information about the organophosphorus class of insecticides, see the section titled “Organophosphorus Insecticides: Dialkyl Phosphate Metabolites.”

Organophosphorus insecticide (CAS number)	**Primary urinary metabolite** (CAS number)
Chlorpyrifos (2921-88-2) Chlorpyrifos-methyl (5598-13-0)	3,5,6-Trichloro-2-pyridinol (6515-38-4)
Coumaphos (56-72-4)	3-Chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol
Diazinon (333-41-5)	2-Isopropyl-4-methyl-6-hydroxypyrimidine (2814-20-2)
Malathion (121-75-5)	Malathion dicarboxylic acid (1190-28-9)
Ethyl parathion (56-38-2) Methyl parathion (298-00-0)	*para*-Nitrophenol (100-02-7)
Pirimiphos-methyl (29232-93-7)	2-(Diethylamino)-6-methylpyrimidin-4-ol/one

Chlorpyrifos
CAS No. 2921-88-2

Chlorpyrifos-methyl
CAS No. 5598-13-0

General Information

The chemical 3,5,6-trichloro-2-pyridinol (TCPy) is a metabolite of chlorpyrifos and chlorpyrifos-methyl. Chlorpyrifos is a broad spectrum organophosphorus insecticide that has been widely used to control insects on food crops such as corn. It also has been applied directly on animals to kill mites, applied to structures to kill termites, and sprayed to kill mosquitoes. Approximately 21-24 million pounds per year were used domestically from 1987-1998. After 2001, chlorpyrifos was no longer registered for indoor residential uses in the United States; pre- and post-construction structural applications for termite control were to be phased out by 2005 (U.S.EPA, 2002). Chlorpyrifos-methyl is an organophosphorus insecticide also used in agriculture and not registered for residential use. Approximately 80,000 pounds are used per year. Chlorpyrifos is degraded in agricultural soils with a half-life of several months, and on plants for days to several weeks. It has low leachability, staying bound to soil particles, and is infrequently detected in ground water (IPCS, 1999; USGS, 2007), but can be detected in streams receiving runoff from application sites. Chlorpyrifos is very toxic to fish and aquatic invertebrates and shows modest degrees of bioconcentration.

The general population may be exposed to chlorpyrifos via oral, dermal, and inhalation routes. Estimated intakes from diet and water have not exceeded recommended intake limits, although some tolerances for specific food crops have been reduced in the past to avoid exceeding recommended intake limits for total dietary intake in special groups (U.S.EPA, 2002). Exposure can also result from contact with contaminated surfaces, air, and dust. For instance, in 142 urban homes and preschools in North Carolina, chlorpyrifos and TCPy were detected in all indoor air and dust samples (Morgan et al., 2005). Chlorpyrifos is not well absorbed through the skin but dermal exposure can be significant when other routes of exposure are low. Inhalational and dermal routes of exposure are important in pesticide formulators and applicators. Chlorpyrifos is

Urinary 3,5,6-Trichloro-2-pyridinol

Metabolite of Chlorpyrifos and Chlorpyrifos-methyl

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.77** (1.46-2.14)	**1.70** (1.40-2.20)	**3.50** (2.50-5.20)	**7.30** (4.80-10.0)	**10.0** (7.70-15.0)	1994
	01-02	**1.76** (1.52-2.03)	**2.22** (1.90-2.61)	**4.95** (4.55-5.29)	**8.80** (7.74-9.77)	**12.4** (10.4-15.3)	2509
Age group							
6-11 years	99-00	**2.88** (1.99-4.16)	**2.80** (1.60-4.90)	**7.09** (3.40-10.0)	**12.0** (7.70-17.0)	**16.0** (10.0-28.0)	481
	01-02	**2.67** (2.13-3.35)	**3.09** (2.50-4.22)	**6.36** (4.97-7.97)	**10.9** (7.98-15.3)	**15.3** (11.5-24.0)	573
12-19 years	99-00	**2.37** (1.89-2.97)	**2.10** (1.60-3.00)	**4.50** (2.90-7.10)	**8.10** (5.50-14.0)	**12.5** (8.00-24.0)	681
	01-02	**2.71** (2.19-3.35)	**3.57** (2.66-4.34)	**6.60** (5.61-7.59)	**11.3** (8.66-15.1)	**18.0** (13.7-23.7)	823
20-59 years	99-00	**1.53** (1.29-1.83)	**1.50** (1.30-1.80)	**2.90** (2.20-4.30)	**5.90** (3.90-8.90)	**8.90** (6.70-11.0)	832
	01-02	**1.51** (1.32-1.72)	**1.91** (1.44-2.26)	**4.44** (3.90-4.80)	**7.78** (7.00-8.91)	**10.9** (9.52-12.4)	1113
Gender							
Males	99-00	**1.92** (1.60-2.32)	**1.90** (1.50-2.40)	**3.60** (2.70-5.60)	**7.40** (5.04-10.0)	**10.0** (7.70-16.0)	972
	01-02	**2.13** (1.81-2.51)	**2.67** (2.20-3.25)	**5.37** (4.87-6.25)	**9.63** (8.20-11.5)	**14.9** (10.9-18.9)	1183
Females	99-00	**1.63** (1.31-2.02)	**1.50** (1.20-2.00)	**3.30** (2.30-5.30)	**7.20** (4.30-12.0)	**11.0** (7.20-16.0)	1022
	01-02	**1.45** (1.24-1.70)	**1.74** (1.39-2.21)	**4.38** (3.72-4.95)	**7.71** (6.30-9.20)	**10.4** (8.47-13.2)	1326
Race/ethnicity							
Mexican Americans	99-00	**1.61** (1.31-2.00)	**1.67** (1.30-2.20)	**3.20** (2.60-3.80)	**5.10** (3.80-8.40)	**7.40** (5.10-17.0)	697
	01-02	**2.02** (1.79-2.28)	**2.63** (2.24-3.01)	**4.60** (4.05-5.39)	**9.02** (7.04-10.8)	**12.2** (10.8-15.7)	660
Non-Hispanic blacks	99-00	**2.17** (1.59-2.97)	**1.90** (1.43-2.80)	**4.30** (2.50-8.30)	**9.40** (6.40-13.7)	**13.0** (9.40-26.0)	521
	01-02	**2.19** (1.68-2.84)	**2.89** (2.28-3.47)	**5.47** (4.77-6.96)	**9.27** (7.47-11.6)	**12.3** (10.1-16.8)	701
Non-Hispanic whites	99-00	**1.76** (1.51-2.05)	**1.70** (1.50-2.10)	**3.50** (2.50-4.86)	**7.10** (4.30-11.0)	**10.0** (7.20-14.0)	602
	01-02	**1.71** (1.43-2.03)	**2.15** (1.62-2.64)	**4.94** (4.44-5.37)	**8.68** (7.47-9.97)	**12.4** (9.77-15.9)	947

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.4 and 0.4.

rapidly absorbed following ingestion. Once absorbed, phosphorothioates such as chlorpyrifos are metabolically activated to the "oxon" form which has greater toxicity than the parent insecticide. Metabolic hydrolysis leads to the formation of TCPy, dialkyl phosphate metabolites (see section titled "Organophosphorus Insecticides: Dialkyl Phosphate Metabolites"), and other metabolites. Chlorpyrifos is eliminated from the body primarily in the urine with a half-life of approximately 27 hours (Nolan et al., 1984). In addition to being a metabolite of chlorpyrifos and chlorpyrifos-methyl in the body, TCPy can also occur in the environment from the breakdown of the parent compounds. TCPy is more persistent in the environment than chlorpyrifos itself (U.S.EPA, 2002). Thus, the detection of TCPy in a person's urine may reflect exposure to the environmental degradates.

Human health effects from chlorpyrifos or chlorpyrifos-methyl at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Chlorpyrifos and chlorpyrifos-methyl both demonstrate moderate acute toxicity in animal studies. These organophosphorus insecticides share a mechanism of toxicity: inhibition of the activity of acetylcholinesterase enzymes in the nervous system, resulting in excess acetylcholine at nerve terminals, and producing acute symptoms such as nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. The metabolite TCPy does not inhibit acetylcholinesterase enzymes. Overt cholinergic toxicity from chlorpyrifos has been described following suicidal ingestion and unintentional high level occupational exposure. Based on animal data and human cholinesterase monitoring during occupational exposure, ubiquitous low-level environmental exposures in humans would not be expected to result in inhibition of cholinesterase activity. Recent *in vitro* and *in vivo* animal studies suggest that effects on neuronal morphogenesis, neurotransmission, and behavior may occur at systemically nontoxic doses or at doses of chlorpyrifos that do not result in cholinergic signs (Aldridge et al., 2005; Betancourt et al., 2006; Howard et al., 2005; Ricceri et al., 2006; Roy et al., 2005; Slotkin et al., 2006*a*, 2006*b*). In pesticide applicators, chronic exposure to chlorpyrifos may be associated with slight alterations in some components of neurophysiologic testing (Steenland et al., 2000). Two observational studies of pregnant women and their offspring exposed to chlorpyrifos at environmental levels have found inconsistent relationships with birth outcomes of weight and length (Eskenazi et al.,

Urinary 3,5,6-Trichloro-2-pyridinol (creatinine corrected)

Metabolite of Chlorpyrifos and Chlorpyrifos-methyl

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.58** (1.35-1.85)	**1.47** (1.24-1.74)	**2.85** (2.12-3.59)	**5.43** (4.22-6.68)	**8.42** (6.25-11.6)	1994
	01-02	**1.73** (1.49-2.01)	**1.88** (1.64-2.24)	**3.76** (2.91-4.62)	**6.15** (4.99-8.31)	**9.22** (6.94-12.3)	2508
Age group							
6-11 years	99-00	**3.11** (2.31-4.19)	**3.20** (2.05-4.80)	**6.39** (4.14-8.19)	**10.1** (7.26-14.0)	**14.1** (10.1-21.0)	481
	01-02	**3.48** (2.80-4.32)	**3.76** (3.17-4.36)	**6.22** (4.88-8.57)	**12.2** (7.24-24.4)	**16.9** (12.1-38.0)	573
12-19 years	99-00	**1.60** (1.34-1.91)	**1.45** (1.21-1.81)	**2.58** (1.97-3.92)	**4.82** (3.44-6.16)	**6.16** (4.43-10.6)	681
	01-02	**2.09** (1.72-2.55)	**2.24** (1.92-2.66)	**3.97** (3.30-4.72)	**6.33** (5.62-7.89)	**10.3** (7.65-15.2)	822
20-59 years	99-00	**1.41** (1.23-1.62)	**1.33** (1.12-1.58)	**2.37** (1.87-3.01)	**4.29** (3.53-5.56)	**6.42** (5.11-9.02)	832
	01-02	**1.49** (1.30-1.71)	**1.64** (1.39-1.88)	**3.11** (2.60-3.91)	**5.50** (4.33-7.23)	**7.44** (5.80-11.0)	1113
Gender							
Males	99-00	**1.48** (1.27-1.72)	**1.44** (1.19-1.68)	**2.54** (2.05-3.38)	**4.95** (3.84-6.54)	**7.63** (5.65-11.0)	972
	01-02	**1.71** (1.47-2.00)	**1.88** (1.57-2.22)	**3.46** (2.82-4.28)	**5.93** (4.90-9.24)	**10.5** (6.94-14.3)	1183
Females	99-00	**1.69** (1.42-2.01)	**1.51** (1.25-1.85)	**2.97** (2.24-4.01)	**5.63** (4.27-7.39)	**8.44** (5.79-13.3)	1022
	01-02	**1.75** (1.49-2.07)	**1.93** (1.59-2.33)	**3.91** (3.06-4.85)	**6.47** (5.00-8.11)	**8.98** (6.83-11.8)	1325
Race/ethnicity							
Mexican Americans	99-00	**1.46** (1.20-1.77)	**1.44** (1.05-1.93)	**2.39** (2.09-2.96)	**3.86** (3.24-5.08)	**5.85** (3.88-9.57)	697
	01-02	**1.86** (1.63-2.12)	**2.06** (1.83-2.35)	**3.81** (3.17-4.56)	**6.52** (5.64-7.58)	**9.00** (7.66-11.8)	660
Non-Hispanic blacks	99-00	**1.47** (1.09-1.99)	**1.33** (.940-1.91)	**2.86** (1.58-5.05)	**5.91** (4.05-8.93)	**9.02** (5.91-13.7)	521
	01-02	**1.56** (1.19-2.03)	**1.92** (1.57-2.40)	**3.53** (2.85-4.28)	**5.58** (4.80-6.07)	**7.06** (5.88-8.82)	700
Non-Hispanic whites	99-00	**1.66** (1.45-1.91)	**1.55** (1.31-1.83)	**2.93** (2.09-3.97)	**5.56** (4.21-6.75)	**8.44** (6.25-12.3)	602
	01-02	**1.78** (1.49-2.14)	**1.95** (1.56-2.35)	**3.82** (2.70-4.97)	**6.55** (4.88-10.5)	**9.98** (7.00-13.7)	947

2004; Perera et al., 2003; Whyatt et al., 2004).

Some reproductive and teratogenic effects in animal testing were only observed at high doses of chlorpyrifos that caused overt maternal toxicity. Chlorpyrifos is not considered to be mutagenic or carcinogenic (NTP, 1992; U.S.EPA, 2002). Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html and from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary TCPy levels reflect recent exposure. Levels of TCPy in the U.S. subsamples of NHANES 1999-2000 and 2001-2002 (CDC, 2005) appear roughly similar to values reported for a nonrandom subsample of NHANES III (1988-1994) participants (Hill et al., 1995) and were similar to levels reported in studies of healthy adults in Germany (Koch et al., 2001) and Italy (Aprea et al., 1999). In a probability-based sample of 102 Minnesota children aged 3-13 years, the weighted population mean of TCPy measurements was approximately three times higher (Adgate, 2001) than the corresponding values reported for the group aged 6-11 years from the NHANES 1999-2000 subsample (CDC, 2005). MacIntosh et al. (1999) reported mean urinary TCPy levels in a sample of Maryland adults that were about three times higher than adults in the U.S. population (CDC, 2005). Of 482 pregnant women living in an agricultural community, 76% had detectable levels of TCPy and levels were similar to those reported for NHANES 1999-2000 (Eskenazi et al., 2004). Other small studies of environmentally-exposed persons have shown a high frequency of detecting low levels of TCPy.

Following crack-and-crevice application of chlorpyrifos in their homes, urinary TCPy levels in children were reported not to have increased (Hore et al., 2005). Chlorpyrifos levels in house dust and hand rinses did not correlate with levels of TCPy in urine (Lioy et al., 2000). Replacing conventional diets with organic diets in 23 children led to about a fourfold decrease in urinary levels of chlorpyrifos; median urinary levels on the conventional diet were several fold higher than those in the NHANES 1999-2000 subsample (Lu et al., 2006). Measurements of urinary TCPy in single spot urine collections show variability over time in environmentally exposed individuals and are poorly correlated between collections, suggesting changing low-level exposure and variance in collection timing with respect to exposure (Meeker et al., 2005). Estimation of dose or intake based on the urinary excretion of TCPy indicates that environmental doses are generally below recommended limits (Hore et al., 2005; Koch et al., 2001).

In Iowa farm families using several different pesticides, but not chlorpyrifos, the geometric mean urinary TCPy levels were similar in parents and children, but levels were roughly four to six times higher than the geometric means in the U.S. representative subsample of NHANES 1999-2000 (CDC, 2005; Curwin et al., 2007). In Minnesota and South Carolina farmers who used chlorpyrifos, urinary TCPy levels averaged about sixfold higher than those in the NHANES 1999-2000 subsample (Mandel et al., 2005; CDC, 2005). Urinary levels of TCPy have been found to be hundredsfold higher for chlorpyrifos manufacturing workers (Burns et al., 2006) and episodically many times higher for pesticide applicators than median levels from NHANES 1999-2000 (CDC, 2005).

Finding a measurable amount of TCPy in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of TCPy provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of chlorpyrifos or chlorpyrifos-methyl than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Coumaphos

CAS No. 56-72-4

General Information

The chemical 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol is a metabolite of coumaphos. First registered in 1958, coumaphos is an organophosphorus insecticide that is used to control ticks, lice, mites, and arthropod pests on beef cattle, dairy cows, swine, and certain other farm animals. Also, it has limited use in controlling mites in honeybee hives. It is not registered for uses on food crops, ornamentals, or for residential use. Coumaphos may enter the environment from spillage of animal dipping and spraying solutions (U.S.EPA, 2000). Coumaphos is generally immobile in soils and can persist for up to a year in some types of soils. It degrades to chlorferon, 6-hydroxyl-3-methylbenzofuran, and alkyl phosphates. Coumaphos is highly toxic to birds and aquatic invertebrates and moderately toxic to fish.

General population exposure to coumaphos is unlikely, though exposure through dietary meat and milk intake is possible. Estimated intakes from diet and water have not exceeded recommended intake limits (U.S.EPA, 2000). Farm and animal workers may have higher exposures as a result of absorption through dermal and inhalational routes. Once absorbed, phosphorothioates such as coumaphos are metabolically activated to the "oxon" form which has greater toxicity than the parent insecticide. Metabolic hydrolysis leads to the formation of 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol, dialkyl phosphate metabolites (see section titled "Organophosphorus Insecticides: Dialkyl Phosphate Metabolites"), and other metabolites. Animal studies indicate elimination in the urine over a period of a week.

Human health effects from coumaphos at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Coumaphos is considered to be an organophosphorus insecticide of moderate-to-high acute toxicity in animal studies. At high doses, coumaphos and other organophosphorus insecticides share a mechanism of toxicity: inhibition of the activity of acetylcholinesterase enzymes in the nervous system, resulting in excess acetylcholine at nerve terminals, and producing acute symptoms such as nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. Toxic effects below doses that cause inhibition of acetylcholinesterase are unknown, e.g., reproductive effects such as decrease litter size are unlikely at doses that do not inhibit acetylcholinesterase (Astroff et al., 1998). Coumaphos is not considered mutagenic and rated by the U.S.EPA as not likely to be carcinogenic in humans (U.S.EPA, 2000). Additional information about pesticides is available from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol reflect recent exposure. In the NHANES 2001-2002 subsample, most of the measurements of 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol in urine were below the limit of detection, though the 95th percentile was 0.200 µg/L for the non-Hispanic black subsample (CDC, 2005). In a nonrandom study of 140 adults and children in the United States, Olsson et al. (2003) found that urinary levels of 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol were below the limit of detection.

Finding a measurable amount of 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of 3-chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of coumaphos than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 3-Chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol

Metabolite of Coumaphos

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2481
Age group							
6-11 years	01-02	*	< LOD	< LOD	< LOD	.200 (<LOD-.210)	567
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	815
20-59 years	01-02	*	< LOD	< LOD	< LOD	< LOD	1099
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1169
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1312
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	659
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	.200 (<LOD-.270)	701
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	920

Limit of detection (LOD, see Data Analysis section) for Survey year 01-02 is 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary 3-Chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol (creatinine corrected)

Metabolite of Coumaphos

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2480
Age group							
6-11 years	01-02	*	< LOD	< LOD	< LOD	.670 (<LOD-1.27)	567
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	814
20-59 years	01-02	*	< LOD	< LOD	< LOD	< LOD	1099
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1169
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1311
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	659
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	.380 (<LOD-.560)	700
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	920

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Diazinon

CAS No. 333-41-5

General Information

The chemical 2-isopropyl-4-methyl-6-hydroxypyrimidine is a metabolite of diazinon, an organophosphorus insecticide that is used to control insects on nuts, fruits, vegetable, and forage crops. It is also used for cattle ear tag applications to control flies and ticks and, in the past, in some pest strips. Most granular formulations, aerial, seed and foliar applications are planned to be phased out (U.S.EPA, 2004). Prior to 2000, diazinon was widely used in residential and garden application, but these uses have been phased out; since 2004, diazinon cannot be sold for residential use. Before these restrictions, about 13 million pounds of diazinon were used annually on agricultural sites in the United States. Diazinon is biologically and chemically degraded in soils with a half-life of about a few weeks. It has been infrequently detected in general groundwater sampling but has been detected in streams receiving runoff from application sites (IPCS, 1998; USGS, 2007). It is toxic to birds, and particularly when it was ingested in granular form, diazinon produced wild bird kills before use restrictions were in place. Fish and aquatic invertebrates show modest degrees of bioconcentration and are very sensitive to toxic effects.

Human exposure to diazinon from dietary sources is expected to be low due to its limited applications to food crops and due to its rapid degradation. Estimated intakes from diet and water do not exceed recommended intake limits (U.S.EPA, 2004). Inhalational and dermal routes of exposure can be significant for pesticide applicators. Diazinon is not well-absorbed through the skin, but is rapidly absorbed orally (IPCS, 1998). Once absorbed, phosphorothioates such as diazinon are metabolically activated to the “oxon” form which has greater toxicity. Metabolic hydrolysis leads to the formation of 2-isopropyl-4-methyl-6-hydroxypyrimidine, dialkyl phosphate metabolites (see section titled “Organophosphorus Insecticides: Dialkyl Phosphate Metabolites”), and other metabolites. Experimental diazinon exposure in people has demonstrated its rapid elimination into urine, as inferred

Urinary 2-Isopropyl-4-methyl-6-hydroxypyrimidine

Metabolite of Diazinon

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1842
	01-02	*	< LOD	< LOD	< LOD	< LOD	2535
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	454
	01-02	*	< LOD	< LOD	< LOD	**1.45** (<LOD-3.11)	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	632
	01-02	*	< LOD	< LOD	< LOD	< LOD	829
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	756
	01-02	*	< LOD	< LOD	< LOD	< LOD	1126
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	894
	01-02	*	< LOD	< LOD	< LOD	< LOD	1191
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	948
	01-02	*	< LOD	< LOD	< LOD	< LOD	1344
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	644
	01-02	*	< LOD	< LOD	< LOD	< LOD	678
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	484
	01-02	*	< LOD	< LOD	< LOD	**1.49** (<LOD-2.05)	700
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	554
	01-02	*	< LOD	< LOD	< LOD	< LOD	956

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 7.2 and 0.7.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

from dialkyl phosphate metabolite excretion (Garfitt et al., 2002). In animals, diazinon does not accumulate in tissues (IPCS, 1998). In addition to being a human metabolite of diazinon, 2-isopropyl-4-methyl-6-hydroxypyrimidine can also occur in the environment from the breakdown of the parent compound. Thus, the detection of 2-isopropyl-4-methyl-6-hydroxypyrimidine in a person's urine may reflect exposure to the environmental degradate.

Human health effects from diazinon at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Diazinon has moderate acute toxicity in animal studies. At high doses, diazinon and other organophosphorus insecticides share a mechanism of toxicity: inhibition of the activity of acetylcholinesterase enzymes in the nervous system, resulting in excess acetylcholine at nerve terminals, and producing acute symptoms such as nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. Intoxications in humans from intentional overdose, agricultural, and indoor applications have been documented. There has been only limited study of diazinon at systemically non-toxic doses that do not result in cholinergic signs (Anthony et al., 1986 Rajendra et al., 1986; Seifert and Pewnim, 1992). Diazinon is not considered to be a mutagen, animal carcinogen, teratogen, or reproductive toxicant (IPCS, 1998). The U.S.EPA considers diazinon unlikely to be carcinogenic in humans. Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html and from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of 2-isopropyl-4-methyl-6-hydroxypyrimidine reflect recent exposure. In two nonrandom samples of United States adults and children, 2-isopropyl-4-methyl-6-hydroxypyrimidine was detectable in 57% and 43% of the 130 and 140 participants, respectively (Baker et al., 2000; Olsson et al., 2003). In the U.S. subsamples of NHANES 1999-2000 and 2001-2002, most of the measurements of 2-isopropyl-4-methyl-6-hydroxypyrimidine in urine were below the limit of detection, although the 95th percentiles for children 6-11 years old and for non-Hispanic blacks were 1.45 and 1.49 µg/L, respectively, in the 2001-2002 subsample (CDC,

Urinary 2-Isopropyl-4-methyl-6-hydroxypyrimidine (creatinine corrected)

Metabolite of Diazinon

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1842
	01-02	*	< LOD	< LOD	< LOD	< LOD	2534
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	454
	01-02	*	< LOD	< LOD	< LOD	2.72 (<LOD-4.45)	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	632
	01-02	*	< LOD	< LOD	< LOD	< LOD	828
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	756
	01-02	*	< LOD	< LOD	< LOD	< LOD	1126
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	894
	01-02	*	< LOD	< LOD	< LOD	< LOD	1191
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	948
	01-02	*	< LOD	< LOD	< LOD	< LOD	1343
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	644
	01-02	*	< LOD	< LOD	< LOD	< LOD	678
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	484
	01-02	*	< LOD	< LOD	< LOD	1.76 (<LOD-3.48)	699
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	554
	01-02	*	< LOD	< LOD	< LOD	< LOD	956

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

2005). In 23 children, urinary 2-isopropyl-4-methyl-6-hydroxypyrimidine was detected in less than 14% of multiple samples collected during varied diets (Lu et al., 2006). In a small number of men visiting fertility clinics in Missouri and Minnesota, Swan et al. (2003) found that 2-isopropyl-4-methyl-6-hydroxypyrimidine was detectable in 96% and 58% of the subjects. In 54 Canadian greenhouse workers, urinary 2-isopropyl-4-methyl-6-hydroxypyrimidine levels were below the limit of detection (Bouchard et al., 2006).

Finding a measurable amount of 2-isopropyl-4-methyl-6-hydroxypyrimidine in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of 2-isopropyl-4-methyl-6-hydroxypyrimidine provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of diazinon than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Malathion

CAS No. 121-75-5

General Information

Malathion dicarboxylic acid is a metabolite of malathion, which is an organophosphorus insecticide that is used on a wide variety of agricultural crops, as well as lawns, gardens, ornamental trees, shrubs, and plants. It is registered for use in public health mosquito control, in fruit fly control, and in government programs such as the USDA's Boll Weevil Eradication Program. Most of the estimated 15 million pounds used annually are applied to cotton (U.S.EPA, 2006). When malathion is used on food or feed crops, usually only a small fraction of the crop is treated. It has a short half-life in soils and water and is not considered persistent in the environment. Malathion is infrequently detected in groundwater sampling (USGS, 2007). It is moderately to highly toxic to fish, depending on the species. It is highly toxic to aquatic invertebrates and rare fish kills have been reported from wide area applications onto surface waters and runoff into waters. Malathion is also used medically in lotion form (0.5%) to kill body lice.

Limited general population exposure occurs through the diet. Estimated intakes for the general population have not exceeded recommended intake limits. Pesticide applicators and agricultural workers can have higher exposures via dermal, inhalational, or oral routes (U.S.EPA, 2006). Malathion is slowly absorbed through the skin, but is more rapidly and efficiently absorbed via ingestion. Once they are absorbed, phosphorothioates such as malathion are metabolically activated to the "oxon" forms which have greater toxicity than the parent insecticide. Metabolism of malathion leads to the formation of malathion monocarboxylic acid, malathion dicarboxylic acid, dialkyl phosphate metabolites (see section titled "Organophosphorus Insecticides: Dialkyl Phosphate Metabolites"), and other metabolites. Malathion is rapidly eliminated from the body within 12-24 hours (Bouchard et al., 2003). About 31-35% of oral doses of malathion are excreted in the urine as malathion monocarboxylic acid (Krieger and Dinoff, 2000). In addition to being a metabolite of malathion, malathion dicarboxylic acid can also occur in the environment from the breakdown of the parent compound. Thus, the detection of malathion dicarboxylic acid in a person's urine may also reflect exposure to the environmental degradate.

Human health effects from malathion at low environmental doses or at biomonitored levels from low environmental exposures are unknown. At high doses, malathion and other organophosphorus insecticides share a common mechanism of toxicity: inhibition of the activity of acetylcholinesterase enzymes in the nervous system, resulting in excess acetylcholine at nerve terminals, and producing acute symptoms such as nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. Compared with other organophosphorus insecticides, malathion has low acute toxicity. Severe toxicity or deaths have been reported from

Urinary Malathion dicarboxylic acid

Metabolite of Malathion

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1920
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	**2.80** (<LOD-5.50)	453
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	807
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	983
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	498
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	580

Limit of detection (LOD, see Data Analysis section) for Survey year 99-00 is 2.64.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

direct ingestion of agricultural strength solutions. Toxicity from unprotected bystander exposure during applications is rare (U.S.EPA, 2006). Human studies of single oral doses between 0.5 and 5.0 mg/kg/day have shown no acetylcholinesterase inhibition or other short term effects (IPCS, 2003). Malathion does not appear to produce human reproductive or teratogenic effects at environmental levels of exposure (Grether et al., 1987; Thomas et al., 1990), and it is not considered an animal teratogen or a reproductive toxicant. Malathion itself has not been considered genotoxic (U.S.EPA, 2006), but isomalathion, a malaoxon metabolite and a technical grade impurity tested positive in some chromosomal tests (Blasiak et al., 1999; Flessel et al., 1993; Giri et al., 2002; Pluth et al., 1996. IARC considers malathion not classifiable as a human carcinogen. Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html and from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Levels of urinary malathion dicarboxylic acid reflect recent exposure. The 95th percentile urinary levels of malathion dicarboxylic acid in both urban and nonurban Minnesota children aged 3-13 years (adjusted for sociodemographic variables) in 1997 were several-fold higher than the analytical detection limits reported for children aged 6-11 years in the U.S. representative subsample from NHANES 1999-2000 (Adgate, 2001; CDC, 2005). Malathion dicarboxylic acid was infrequently detected in multiple samples from 80 Maryland residents in 1995-96 (MacIntosh et al., 1999). Of 382 pregnant women living in an agricultural community, 30% had detectable levels of malathion dicarboxylic acid at a detection limit about tenfold lower than the detection limit in the NHANES 1999-2000 analyses (Eskenazi et al., 2004). A study of 13 children from an agricultural region of Washington State reported median levels that were below the detection limit in the NHANES 1999-2000 subsample (Kissel et al., 2005). Replacing conventional diets with organic diets in 23 children led to a tenfold decrease in urinary levels of malathion dicarboxylic acid; median urinary levels on the conventional diet were similar to the detection limit in the NHANES 1999-2000 subsample (CDC, 2005; Lu et al., 2006). A study of agricultural workers reported preshift urinary levels of malathion dicarboxylic acid that were twofold to eightfold higher than detection limits in the NHANES 1999-2000 subsample (Krieger and Dinoff, 2000); some of the postshift urine levels in duster-applicators were thousandsfold higher than the detection limits in the NHANES 1999-2000 subsample, but cholinesterase activity was not affected.

Finding a measurable amount of malathion dicarboxylic acid in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of malathion dicarboxylic acid provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of malathion than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Malathion dicarboxylic acid (creatinine corrected)

Metabolite of Malathion

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1920
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	**3.74** (<LOD-5.50)	453
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	807
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	983
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	498
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	580

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Methyl Parathion

CAS No.298-00-0

Ethyl Parathion

CAS No. 56-38-2

General Information

Para-nitrophenol is a metabolite of the insecticides methyl parathion, ethyl parathion, O-ethyl-O-(4-nitrophenyl) phenylphosphonothioate, and of the chemical nitrobenzene. Methyl parathion use is highly restricted, with limited applications in agriculture. Many previous registered agricultural uses of methyl parathion have been cancelled (U.S.EPA, 2003). It had been applied to cotton, and to a lesser extent, on cereal grains. In the 1990s, peak domestic use was as high as 5-6 million pounds per year. Methyl parathion is not registered for residential use in the United States. Ethyl parathion, first registered in 1948, was once a restricted-use insecticide with limited applications on certain agricultural crops, but by 2003, all registered uses were voluntarily cancelled (U.S.EPA, 2000). Methyl parathion has low water solubility, binds tightly to soils resulting in low leachability, and has a short half-life in soils and on plants. Ethyl and methyl parathion are infrequently detected in groundwater sampling (USGS, 2007). Both are toxic to birds, fish, and aquatic invertebrates.

Given its limited use, the potential for human exposure to either ethyl or methyl parathion through the diet or drinking water is low. Estimated intakes from diet and drinking water have been below recommended limits. Increased risk of exposure via dermal, pulmonary, and oral routes can occur in pesticide and agricultural workers (Muttray et al., 2006). In animal studies, methyl parathion was rapidly absorbed after ingestion, more slowly absorbed through the skin, and eliminated rapidly from the body after absorption (Kramer et al., 2002; Morgan et al., 1977). Once absorbed, phosphorothioates such as methyl and ethyl parathion are metabolically activated to the “oxon” forms which have greater toxicity than the parent insecticides. Metabolism of ethyl or methyl parathion leads to the formation of para-nitrophenol, dialkyl phosphate metabolites (see section titled “Organophosphorus Insecticides: Dialkyl Phosphate

Urinary *para*-Nitrophenol

Metabolite of Ethyl Parathion, Methyl Parathion, and Nitrobenzene

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**2.50** (1.40-4.50)	**5.00** (2.90-11.0)	1989
	01-02	*	< LOD	**1.33** (1.21-1.48)	**2.70** (2.40-3.02)	**3.71** (3.41-4.00)	2477
Age group							
6-11 years	99-00	*	< LOD	**.940** (<LOD-2.40)	**2.67** (1.70-3.80)	**4.30** (2.70-6.40)	479
	01-02	*	**.790** (<LOD-.910)	**1.49** (1.36-1.61)	**2.89** (2.22-3.58)	**4.10** (3.01-4.74)	565
12-19 years	99-00	*	< LOD	< LOD	**3.40** (1.60-5.70)	**5.70** (2.60-19.0)	680
	01-02	*	**.730** (<LOD-.910)	**1.45** (1.32-1.61)	**2.66** (2.15-3.11)	**3.34** (3.11-4.01)	813
20-59 years	99-00	*	< LOD	< LOD	**2.30** (1.20-5.70)	**4.50** (2.30-16.0)	830
	01-02	*	< LOD	**1.28** (1.09-1.47)	**2.69** (2.32-3.10)	**3.72** (3.37-4.24)	1099
Gender							
Males	99-00	*	< LOD	< LOD	**2.50** (1.40-4.50)	**4.50** (2.50-14.0)	971
	01-02	*	**.770** (.300-.910)	**1.50** (1.32-1.67)	**3.00** (2.70-3.27)	**4.10** (3.37-4.92)	1164
Females	99-00	*	< LOD	< LOD	**2.50** (1.30-5.70)	**5.70** (2.90-9.50)	1018
	01-02	*	< LOD	**1.19** (.990-1.37)	**2.26** (1.92-2.69)	**3.46** (3.18-3.71)	1313
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**1.70** (<LOD-3.50)	**5.80** (2.60-24.0)	**22.0** (3.60-36.0)	695
	01-02	*	**.700** (<LOD-.850)	**1.32** (1.10-1.57)	**2.62** (1.91-3.44)	**3.85** (2.70-6.05)	660
Non-Hispanic blacks	99-00	*	< LOD	**1.20** (<LOD-2.60)	**2.90** (1.70-6.00)	**4.80** (2.50-9.20)	518
	01-02	*	**.860** (<LOD-1.12)	**1.80** (1.37-2.16)	**3.21** (2.57-4.40)	**5.60** (4.02-6.79)	679
Non-Hispanic whites	99-00	*	< LOD	< LOD	**2.10** (<LOD-6.33)	**4.20** (2.10-11.0)	603
	01-02	*	< LOD	**1.28** (1.13-1.45)	**2.71** (2.30-3.10)	**3.70** (3.28-4.01)	941

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.8 and 0.1.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Metabolites"), and other metabolites. In addition to being a metabolite of methyl and ethyl parathion, para-nitrophenol can also occur in the environment from the breakdown of the parent these organophosphorus pesticides and from nitrobenzene. Thus, the detection of para-nitrophenol in a person's urine may also reflect exposure to the environmental degradate.

Human health effects from parathion or ethyl parathion at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Parathion and methyl parathion have high acute toxicity in animal testing. In large doses, methyl parathion, ethyl parathion, and other organophosphorus insecticides share a common mechanism of toxicity: inhibition of the activity of acetylcholinesterase enzymes in the nervous system, resulting in excess acetylcholine at nerve terminals, and producing acute symptoms such as nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. The metabolite, para-nitrophenol, does not inhibit acetylcholinesterase enzymes. At high animal doses of methyl parathion, retinal atrophy and sciatic nerve degeneration have also been observed (IPCS, 1995; WHO, 2004). Recent *in vitro* and *in vivo* animal studies suggest that parathion may have additional neuronal and glial cell effects at lower doses (Guizzetti et al., 2005; Karanth and Pope et al., 2003; Slotkin et al., 2006; Zurich et al., 2004). Overt cholinergic toxicity and death from methyl and ethyl parathion have been described following suicidal ingestion, accidental exposure, and unintentional acute or chronic high-level occupational exposure (Hill et al., 1990; Jaga and Dharmani, 2006; Lores et al., 1978; Orsorio et al., 1991). Methyl parathion is not considered genotoxic, teratogenic, or generally to have reproductive toxicity at doses below those causing acetylcholinesterase inhibition in most animal studies (IPCS, 1995). IARC does not consider ethyl parathion and methyl parathion classifiable as human carcinogens. U.S.EPA considers methyl parathion unlikely to be carcinogenic to humans, but lists ethyl parathion as a possible human carcinogen. Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html and from U.S. EPA at: http://www.epa.gov/pesticides/.

Urinary *para*-Nitrophenol (creatinine corrected)

Metabolite of Ethyl Parathion, Methyl Parathion, and Nitrobenzene

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**2.08** (1.33-3.91)	**4.25** (2.15-10.2)	1989
	01-02	*	**< LOD**	**.970** (.830-1.10)	**1.91** (1.72-2.03)	**2.89** (2.44-3.23)	2476
Age group							
6-11 years	99-00	*	**< LOD**	**.940** (<LOD-1.95)	**2.80** (1.94-4.00)	**4.20** (3.33-6.70)	479
	01-02	*	**.720** (<LOD-.870)	**1.60** (1.30-1.82)	**2.78** (2.31-3.11)	**3.67** (3.11-4.61)	565
12-19 years	99-00	*	**< LOD**	**< LOD**	**1.80** (1.08-3.04)	**4.00** (1.57-7.29)	680
	01-02	*	**.370** (<LOD-.500)	**.840** (.790-.950)	**1.59** (1.37-1.78)	**2.10** (1.78-2.43)	812
20-59 years	99-00	*	**< LOD**	**< LOD**	**2.00** (1.17-4.25)	**4.29** (2.13-12.3)	830
	01-02	*	**< LOD**	**.880** (.690-1.07)	**1.79** (1.56-2.05)	**2.89** (2.35-3.33)	1099
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**1.90** (1.01-3.39)	**3.39** (1.77-7.55)	971
	01-02	*	**.430** (.310-.530)	**.980** (.850-1.08)	**1.87** (1.57-2.09)	**2.97** (2.14-3.57)	1164
Females	99-00	*	**< LOD**	**< LOD**	**2.26** (1.48-4.88)	**6.92** (2.76-14.1)	1018
	01-02	*	**< LOD**	**.930** (.730-1.23)	**1.96** (1.78-2.15)	**2.82** (2.44-3.06)	1312
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**1.55** (<LOD-3.17)	**4.86** (2.21-21.9)	**17.4** (3.94-47.7)	695
	01-02	*	**.400** (<LOD-.540)	**.930** (.720-1.20)	**1.88** (1.41-2.60)	**3.04** (2.38-3.84)	660
Non-Hispanic blacks	99-00	*	**< LOD**	**.680** (<LOD-1.79)	**2.07** (1.33-3.71)	**3.71** (1.98-7.20)	518
	01-02	*	**.440** (<LOD-.640)	**1.01** (.800-1.31)	**1.73** (1.60-2.21)	**3.01** (2.16-4.30)	678
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**1.97** (<LOD-4.29)	**3.83** (1.97-10.2)	603
	01-02	*	**< LOD**	**.970** (.790-1.13)	**1.96** (1.67-2.26)	**2.93** (2.35-3.45)	941

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

Urinary levels of para-nitrophenol reflect recent exposure. Levels of para-nitrophenol in the NHANES 1999-2000 and 2001-2002 subsamples were similar or slightly lower than those in a nonrandom subsample of NHANES III (1988-1994) participants (CDC, 2005; Hill et al., 1995), and levels were similar or slightly lower that those in a small convenience sample of the U.S. population (Olsson et al., 2003) and in 482 pregnant females from an agricultural region of California (Eskenazi et al., 2004). A study of 13 children from an agricultural region of Washington State reported median levels that were more than threefold higher than median levels in the NHANES 1999-2000 subsample (Kissel et al., 2005). Children and adults living in residences where methyl parathion was applied indoors had urinary levels of para-nitrophenol which were several hundred times higher than those in the NHANES 1999-2000 subsample, and many residents were symptomatic (Barr et al., 2002; CDC, 2005; McCann et al., 2002; Rubin et al., 2002).

Pesticide workers may have much higher levels following pesticide applications. ACGIH recommends a BEI of 0.5 mg (500 µg)/g creatinine for workers at the end of shift. In a study of workers who handle parathion, end-of-shift urinary para-nitrophenol levels ranged from 190 to 410 µg/gram of creatinine (Leng and Lewalter, 1999), a range of values several hundred times higher than levels found in the U.S. general population (CDC, 2005).

Finding a measurable amount of para-nitrophenol in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of para-nitrophenol can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of parathion than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Pirimiphos-methyl

CAS No. 29232-93-7

General Information

The chemical 2-(diethylamino)-6-methylpyrimidin-4-ol/one is a metabolite of the organophosphorus insecticide pirimiphos-methyl, which has limited applications for control of beetles, weevils, and moths on stored grain products such as corn, sorghum, and seed. It has a lesser use as a cattle ear tag application to control flies. Pirimiphos-methyl is not registered for residential use in the United States. It easily hydrolyzes in the environment to 2-(diethylamino)-6-methylpyrimidine and other breakdown products, and it is not considered persistent. Though considered moderately-to-highly toxic in birds, fish, and aquatic invertebrates, occurrence of such toxicity is mitigated by its rapid degradation and its use in closed storage systems.

In the general population, infrequent dietary exposure to pirimiphos-methyl residues may occur from ingestion of food products containing stored corn or other treated grain (FDA, 2003). Estimated intakes from diet and water have not exceeded recommended intake limits (U.S.EPA, 2006). In animal studies, pirimiphos-methyl is rapidly absorbed and metabolized to 12 metabolites, which are mainly excreted in the urine (IPCS, 1992). Once absorbed, phosphorothioates such as pirimiphos-methyl are metabolically activated to the “oxon” form which has greater toxicity than the parent insecticide. Metabolic hydrolysis leads to the formation of 2-(diethylamino)-6-methylpyrimidin-4-ol/one, dialkyl phosphate metabolites (see section titled “Organophosphorus Insecticides: Dialkyl Phosphate Metabolites”), and other metabolites. In addition to being a human metabolite of pirimiphos-methyl in the body, 2-(diethylamino)-6-methylpyrimidin-4-ol/one can also occur in the environment. Thus, the detection of 2-(diethylamino)-6-methylpyrimidin-4-ol/one may also reflect exposure to the environmental degradate.

Human health effects from pirimiphos-methyl at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Pirimiphos-methyl has low acute toxicity in animal studies. At high doses, pirimiphos-methyl and other organophosphorus insecticides share a mechanism of toxicity: inhibition of the activity of acetylcholinesterase enzymes in the nervous system, resulting in excess acetylcholine at nerve terminals, and producing acute symptoms such as nausea, vomiting, cholinergic effects, weakness, paralysis, and seizures. The metabolite 2-(diethylamino)-6-methylpyrimidin-4-ol/one does not inhibit acetylcholinesterase enzymes. Toxic effects below doses that cause inhibition of acetylcholinesterase are unknown. Pirimiphos-methyl is not considered mutagenic, teratogenic, or known to cause delayed neurotoxicity, or reproductive toxicity (IPCS, 1992; U.S.EPA, 2006). Additional information about pesticides is available from U.S. EPA at: http://www.epa.gov/pesticides/.

Biomonitoring Information

Urinary levels of 2-(diethylamino)-6-methylpyrimidin-4-ol/one reflect recent exposure. In the U.S. subsample of NHANES 2001-2002, most of the urinary measurements of 2-(diethylamino)-6-methylpyrimidin-4-ol/one were below the limit of detection, although the 95th percentile was characterized at 0.47 µg/L for the total population (CDC, 2005). In a nonrandom sample of 140 urine specimens obtained from adults and children in the United States, Olsson et al. (2003) detected 2-(diethylamino)-6-methylpyrimidin-4-ol/one in 7.1% of the sampled population.

Finding a measurable amount of 2-(diethylamino)-6-methylpyrimidin-4-ol/one in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of 2-(diethylamino)-6-methylpyrimidin-4-ol/one provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of pirimiphos-methyl than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 2-(Diethylamino)-6-methylpyrimidin-4-ol/one

Metabolite of Pirimiphos-methyl

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	.470 (.210-.770)	2481
Age group							
6-11 years	01-02	*	< LOD	< LOD	.250 (<LOD-.820)	.840 (.210-1.64)	567
12-19 years	01-02	*	< LOD	< LOD	< LOD	.610 (<LOD-1.94)	810
20-59 years	01-02	*	< LOD	< LOD	< LOD	.430 (<LOD-.670)	1104
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	.850 (.300-1.55)	1165
Females	01-02	*	< LOD	< LOD	< LOD	.210 (<LOD-.460)	1316
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	.410 (<LOD-1.15)	669
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	687
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	.500 (.200-.840)	929

Limit of detection (LOD, see Data Analysis section) for Survey year 01-02 is 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary 2-(Diethylamino)-6-methylpyrimidin-4-ol/one (creatinine corrected)

Metabolite of Pirimiphos-methyl

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	.780 (.700-.930)	2481
Age group							
6-11 years	01-02	*	< LOD	< LOD	.680 (<LOD-.950)	1.17 (.740-1.27)	567
12-19 years	01-02	*	< LOD	< LOD	< LOD	.670 (<LOD-1.31)	810
20-59 years	01-02	*	< LOD	< LOD	< LOD	.760 (<LOD-.880)	1104
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	.740 (.580-1.07)	1165
Females	01-02	*	< LOD	< LOD	< LOD	.780 (<LOD-1.08)	1316
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	.780 (<LOD-1.21)	669
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	687
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	.780 (.700-1.00)	929

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Pyrethroid Pesticides

General Information

Pyrethroid pesticides are synthetic analogues of pyrethrins, which are natural chemicals found in chrysanthemum flowers. Pyrethroid pesticides are used to control a wide range of insects in public and commercial buildings, animal facilities, warehouses, agricultural fields, and greenhouses. They are also applied on livestock to control insects. In agriculture, cypermethrin, cyfluthrin, and deltamethrin have been used frequently on cotton. Pyrethroid insecticides are the most common active ingredient in commercially available insect sprays and are also used as structural termiticides. Certain pyrethroid insecticides (such as permethrin, resmethrin, and sumithrin) are also registered for use in mosquito-control programs in the United States. Outside the U.S., deltamethrin has been used for indoor protection against mosquitoes that carry malaria, in some situations replacing the use of DDT. About two million pounds of permethrin and one million pounds of cypermethrin have been applied annually (U.S. EPA, 2006*a*, 2006*b*). Permethrin is also used in skin lotions and shampoos as medical treatments for lice and scabies. Pyrethroid pesticides are generally formulated as complex mixtures of different chemical isomers, solvent oils, and synergists, such as piperonyl butoxide. Pyrethroid pesticides have low volatility, bind to soils, and are rarely detected in ground waters (USGS, 2007). Generally, they are not persistent in the environment due to their rapid degradation within days to several months. This class of pesticides has low toxicity in birds and mammals, but pyrethroids are highly toxic to fish and some aquatic invertebrates, so usage is restricted near water (U.S.EPA, 2002). There are about 30 different pyrethroid pesticides in use. The table shows the urinary pyrethroid metabolites measured in this *Report*.

The general population may be exposed to pyrethroid insecticides primarily from the ingestion of food or from residential use. Estimated intakes from diet and drinking water are below recommended limits. Dermal exposure with the potential for inadvertent ingestion may occur when lotions or shampoos are applied to treat lice or scabies. Pesticide applicators can be exposed to pyrethroid pesticides via dermal and inhalation routes from powders and liquid formulations. Pyrethroids are not well absorbed through the skin (ATSDR, 2003; Woollen et al., 1992). After absorption from inhalation or ingestion, pyrethroids are rapidly metabolized, by either ester hydrolysis or hydroxylation, followed by conjugation, and then eliminated over several days in urine and bile (Kuhn et al., 1999; Leng et al., 1997; Soderlund et al., 2002; Woollen et al., 1992). Unmetabolized pyrethroids have been measured in breast milk, but may be poorly transferred across the placenta (ATSDR, 2003; WHO, 2005).

Human health effects from pyrethroid pesticides at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Compared with other classes of insecticides such as organochlorines, organophosphorus, or carbamate pesticides, pyrethroid pesticides have less acute toxicity in animals and people. They are ranked as having moderate acute oral toxicity. Adverse effects from large doses are related to the action of pyrethroids on the nervous system, where these chemicals prolong sodium channel opening when a nerve cell is depolarized (Shafer et al., 2005; Soderlund et al., 2002). Possible other additional actions on neuroreceptors

Pyrethroid Insecticides Metabolites in this *Report*

Pyrethroid (CAS number)	**Urinary metabolite** (CAS number)
Cyfluthrin (68359-37-5)	4-Fluoro-3-phenoxybenzoic acid (77279-89-1)
Cypermethrin (52315-07-8) Cyfluthrin (68359-37-5) and Permethrin (52645-53-1)	*cis*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (55701-05-8) *trans*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (55701-03-6)
Deltamethrin (52918-63-5)	*cis*-3-(2,2-Dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid
Cyhalothrin (68359-37-5) Cypermethrin (52315-07-8) Deltamethrin (52918-63-5) Fenpropathrin (39515-41-8) Permethrin (52645-53-1) Tralomethrin (66841-25-6)	3-Phenoxybenzoic acid (3739-38-6)

and other ion channels may also explain some pyrethroid effects. Human cases of systemic poisoning are rare and usually result from accidental exposure or intentional ingestion of pyrethroid insecticides. Signs and symptoms of acute pyrethroid poisoning after massive ingestions include agitation, hypersensitivity, tremor, salivation, choreoathetosis, and seizures (ATSDR, 2003; Ray et al., 2000; Soderlund et al., 2002). Concomitant exposure to organophosphorus insecticides may increase pyrethroid toxicity by slowing metabolic clearance of the pyrethroid. In California, cyfluthrin was the most frequent pyrethroid associated with symptomatic effects (irritant respiratory and dermal effects, paresthesias) reported in agricultural workers from 1996 to 2002 (Spencer and O'Malley, 2006). Transient dermal paresthesias have been reported among pesticide applicators after direct contact with certain types of pyrethroid pesticides. No relationship of indoor air or housedust concentrations of permethrin and irritant symptoms was found in a study of urban residents in 80 private homes (Berger-Preiss et al., 2002).

In developing rodents, neurochemical changes in cholinergic, dopaminergic, and catecholaminergic pathways and behavioral changes have been demonstrated at subacute and subchronic doses for some pyrethroid pesticides (Aziz et al., 2001; Elwan et al., 2006; Eriksson and Fredriksson, 1991; Lazarini et al., 2001; Shafer, et al., 2005). The pyrethroids in general use are not considered teratogenic or to have significant reproductive toxicity (ATSDR, 2003; WHO, 2005), though a few pyrethroid pesticides and some metabolites have shown weak or inconsistent estrogenic effects on standardized assays (ATSDR, 2003; Garey and Wolff, 1998; Go et al., 1999; Hu et al., 2003; Kim et al., 2004; Kunimatsu et al., 2002; McCarthy et al., 2006; Moniz et al., 2005). Generally, the pyrethroids are not considered genotoxic in *in vitro* testing or carcinogenic in animal testing (WHO, 2005). IARC considers deltamethrin and permethrin as not classifiable as to their human carcinogenicity. Additional information about pesticides is available from U.S. EPA at: http://www.epa.gov/pesticides/ and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

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Cyfluthrin

CAS No.68359-37-5

General Information

The chemical 4-fluoro-3-phenoxybenzoic acid is a specific metabolite of the pyrethroid insecticide cyfluthrin. Cyfluthrin accounted for one-third of pyrethroid-related worker illnesses reported in California from 1996-2002; most of which were dermal and respiratory irritations (Spencer and O'Malley, 2006). Cyfluthrin is rapidly metabolized and eliminated from the body. Following an indoor application exposure, the mean elimination half-life of cyfluthrin from the plasma was 16 hours (Williams et al., 2003).

Degradation of cyfluthrin to 4-fluoro-3-phenoxybenzoic acid occurs in the environment. Thus, the presence of 4-fluoro-3-phenoxybenzoic acid in urine not only reflects the metabolic transformation of cyfluthrin, but it can also reflect direct exposure to 4-fluoro-3-phenoxybenzoic acid formed in the environment.

Biomonitoring Information

Urinary levels of 4-fluoro-3-phenoxybenzoic acid reflect recent exposure to cyfluthrin or its environmental degradate. Urinary levels of 4-fluoro-3-phenoxybenzoic acid were generally below the limit of detection (0.2 µg/L) in the U.S. representative subsample in NHANES 2001-2002 (CDC, 2005). In an analysis of 217 urine specimens from a nonrandom sample of United States residents, Baker et al. (2004) reported a geometric mean concentration of 4-fluoro-3-phenoxybenzoic acid of 0.95 µg/L. Studies in Germany of 396 children and adolescents (Becker et al., 2006) and 1177 urban adults and children (Heudorf et al., 2001) showed that urinary levels of 4-fluoro-3-phenoxybenzoic acid at the 95th percentile ranged from either slightly higher or lower than the detection limit in the U.S. representative 2001-2002 NHANES subsample (CDC, 2005). Urinary levels for adults and children in these studies were similar (Heudorf et al., 2001, 2006) and estimated daily intakes based on urinary levels in children were considered to be below acceptable daily intakes (Heudorf et al., 2004).

In 57 volunteers entering areas previously spot-sprayed with various pyrethroid pesticides (including cyfluthrin), median urinary levels of 4-fluoro-3-phenoxybenzoic acid were slightly less than the limit of detection in the NHANES 2001-2002 subsample (CDC, 2005; Leng et al., 2003). Seven individuals participating in floor exercises on cyfluthrin treated carpet demonstrated a rise in the urinary excretion of 4-fluoro-3-phenoxybenzoic acid in the 72 hours following the activity (Williams et al., 2003).

Finding a measurable amount of 4-fluoro-3-phenoxybenzoic acid in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of 4-fluoro-3-phenoxybenzoic acid in urine provide physicians and public health officials with reference values so that they can determine whether other people have been exposed to higher levels of cyfluthrin than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 4-Fluoro-3-phenoxybenzoic acid

Metabolite of Cyfluthrin

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1949
	01-02	*	< LOD	< LOD	< LOD	< LOD	2539
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	473
	01-02	*	< LOD	< LOD	< LOD	< LOD	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	662
	01-02	*	< LOD	< LOD	< LOD	< LOD	831
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	814
	01-02	*	< LOD	< LOD	< LOD	< LOD	1128
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	950
	01-02	*	< LOD	< LOD	< LOD	< LOD	1193
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	999
	01-02	*	< LOD	< LOD	< LOD	< LOD	1346
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	666
	01-02	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	517
	01-02	*	< LOD	< LOD	< LOD	< LOD	701
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	594
	01-02	*	< LOD	< LOD	< LOD	< LOD	957

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.2 and 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary 4-Fluoro-3-phenoxybenzoic acid (creatinine corrected)

Metabolite of Cyfluthrin

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1949
	01-02	*	< LOD	< LOD	< LOD	< LOD	2538
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	473
	01-02	*	< LOD	< LOD	< LOD	< LOD	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	662
	01-02	*	< LOD	< LOD	< LOD	< LOD	830
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	814
	01-02	*	< LOD	< LOD	< LOD	< LOD	1128
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	950
	01-02	*	< LOD	< LOD	< LOD	< LOD	1193
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	999
	01-02	*	< LOD	< LOD	< LOD	< LOD	1345
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	666
	01-02	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	517
	01-02	*	< LOD	< LOD	< LOD	< LOD	700
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	594
	01-02	*	< LOD	< LOD	< LOD	< LOD	957

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Cyfluthrin
CAS No.68359-37-5

Cypermethrin
CAS No. 52315-07-8

Permethrin
CAS No.52645-53-1

General Information

Several pyrethroid pesticides are formulated as a mixture of *cis*- and *trans*-isomers. In the body, *cis*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid is a metabolite formed from *cis*-permethrin, *cis*-cypermethrin and *cis*-cyfluthrin. The chemical *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid is a metabolite formed from *trans*-permethrin, *trans*-cypermethrin and *trans*-cyfluthrin. The *cis*-isomer of permethrin has more potent insecticidal activity than *trans*-permethrin. Generally, more of the *trans*-metabolite than the *cis*-metabolite is found in the urine.

The presence of *cis*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid in urine not only reflects the metabolic transformation of any of the three pesticides, *cis*-permethrin, *cis*-cypermethrin, and *cis*-cyfluthrin, but it can also reflect exposure to *cis*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid that is formed in the environment from the degradation of these pesticides (George, 1985; Kuhn et al., 1999). Similarly, the presence of *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid in urine not only reflects the metabolic transformation of any of the three pesticides, *trans*-permethrin, *trans*-cypermethrin, and *trans*-cyfluthrin, but can also reflect exposure to *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid formed in the environment from the degradation of these pesticides (George, 1985; Kuhn et al., 1999).

Biomonitoring Information

Urinary levels of *cis*- or *trans*-3-(2,2-dichlorovinyl)-

Urinary *cis*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid
Metabolite of cis-Permethrin, Cyfluthrin, and cis-Cypermethrin
Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	.270 (.220-.340)	.600 (.490-.710)	1.12 (.770-1.68)	1951
	01-02	*	< LOD	.160 (.120-.210)	.500 (.380-.680)	.890 (.740-1.10)	2539
Age group							
6-11 years	99-00	*	< LOD	.330 (.210-.550)	.740 (.580-1.53)	1.77 (.680-3.15)	468
	01-02	*	< LOD	.110 (<LOD-.200)	.370 (.280-.610)	.730 (.490-.870)	580
12-19 years	99-00	*	< LOD	.300 (.200-.410)	.670 (.460-1.11)	1.44 (.670-2.21)	667
	01-02	*	< LOD	.160 (<LOD-.210)	.440 (.300-.630)	.730 (.630-.920)	831
20-59 years	99-00	*	< LOD	.260 (.200-.330)	.570 (.430-.690)	1.07 (.670-1.80)	816
	01-02	*	< LOD	.170 (.120-.230)	.510 (.400-.740)	.960 (.790-1.28)	1128
Gender							
Males	99-00	*	< LOD	.250 (.200-.310)	.530 (.420-.600)	.790 (.600-1.50)	947
	01-02	*	< LOD	.150 (.110-.200)	.470 (.380-.630)	.880 (.650-1.35)	1193
Females	99-00	*	< LOD	.280 (.220-.380)	.680 (.490-1.08)	1.47 (.950-2.54)	1004
	01-02	*	< LOD	.180 (.120-.240)	.510 (.370-.770)	.890 (.790-1.08)	1346
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	.200 (.110-.240)	.460 (.300-.610)	.730 (.470-1.32)	671
	01-02	*	< LOD	.140 (.110-.180)	.300 (.250-.410)	.510 (.380-.580)	680
Non-Hispanic blacks	99-00	.202 (.155-.262)	.160 (.120-.200)	.380 (.270-.520)	.820 (.490-1.68)	1.68 (.910-5.43)	518
	01-02	*	< LOD	.270 (.220-.350)	.640 (.570-.700)	.850 (.710-1.24)	701
Non-Hispanic whites	99-00	*	< LOD	.270 (.220-.340)	.630 (.460-.780)	1.13 (.740-2.35)	591
	01-02	*	< LOD	.140 (<LOD-.220)	.500 (.340-.790)	.900 (.670-1.28)	957

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.1 and 0.1.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

2,2-dimethylcyclopropane carboxylic acid reflect recent exposure to either their parent pyrethroid pesticides or their environmental degradates. Studies in Germany of 396 children and adolescents (Becker et al., 2006) and 1177 urban adults and children (Heudorf et al., 2001) showed urinary levels of *cis*- and *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acids at the 95th percentile that were similar or slightly less than the 95th percentiles in the U.S. representative NHANES 2001-2002 subsample (CDC, 2005). Urinary levels of the two chemicals in adults were similar to those in children in these studies (Heudorf et al., 2001, 2006). Estimated daily pyrethroid intakes based on urinary levels in the German children were below the acceptable daily tolerances (Heudorf et al., 2004). These studies indicated that intake is mainly from the diet and that dermal absorption contributes little to intake (Heudorf et al., 2004, 2006; Schettgen et al., 2002). Other studies have provided evidence that urinary levels of *cis*- and *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acids in children were related to residential pesticide use and house dust levels (Becker et al., 2006; Lu et al., 2006).

In a study of urban residents in Germany (Berger-Preiss et al., 2002), urinary levels of *cis*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid at the 95th percentile were about half the 95th percentile in the NHANES 2001-2002 subsample (CDC, 2005). In the same residents, urinary *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid levels at the 95th percentile were about one-third of the 95th percentile in the NHANES 2001-2002 subsample (CDC, 2005). In a study of volunteers, the median and 95th percentile of urinary levels of *cis*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid did not increase at 24-72 hours after exposure to nearby pest control operations (Leng et al., 2003); the levels at 24-72 hours were slightly less than the 95th percentile in the NHANES 2001-2002 subsample (CDC, 2005). In these volunteers, median urinary levels of *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid did not increase, though the 95th percentile levels increased several fold after exposure to nearby pest control operations (Leng et al., 2003); the levels at 24-72 hours were slightly less than the 95th percentile in the NHANES 2001-2002 subsample (CDC, 2005)

In a small group of indoor pest-control operators, post-

Urinary *cis*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (creatinine corrected)

Metabolite of cis-Permethrin, Cyfluthrin, and cis-Cypermethrin

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**.260** (.230-.290)	**.540** (.440-.700)	**1.12** (.690-1.59)	1951
	01-02	*	< LOD	**.220** (.200-.250)	**.440** (.370-.520)	**.780** (.640-1.03)	2538
Age group							
6-11 years	99-00	*	< LOD	**.400** (.250-.550)	**.900** (.550-1.67)	**1.67** (.700-2.31)	468
	01-02	*	< LOD	**.250** (<LOD-.320)	**.600** (.430-.700)	**.750** (.640-.890)	580
12-19 years	99-00	*	< LOD	**.200** (.150-.270)	**.430** (.320-.590)	**.810** (.430-1.49)	667
	01-02	*	< LOD	**.160** (<LOD-.200)	**.300** (.250-.380)	**.530** (.370-.780)	830
20-59 years	99-00	*	< LOD	**.260** (.230-.290)	**.530** (.380-.830)	**1.11** (.680-1.59)	816
	01-02	*	< LOD	**.230** (.210-.250)	**.440** (.390-.560)	**.890** (.640-1.08)	1128
Gender							
Males	99-00	*	< LOD	**.220** (.180-.250)	**.420** (.340-.570)	**.800** (.510-1.11)	947
	01-02	*	< LOD	**.170** (.150-.190)	**.350** (.300-.410)	**.680** (.450-1.03)	1193
Females	99-00	*	< LOD	**.290** (.270-.340)	**.640** (.470-1.33)	**1.59** (1.12-2.21)	1004
	01-02	*	< LOD	**.270** (.230-.300)	**.500** (.440-.580)	**.920** (.750-1.11)	1345
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**.190** (.130-.260)	**.380** (.280-.540)	**.710** (.400-1.24)	671
	01-02	*	< LOD	**.170** (.150-.190)	**.300** (.260-.350)	**.540** (.370-.640)	680
Non-Hispanic blacks	99-00	**.138** (.104-.182)	**.120** (.080-.170)	**.260** (.200-.340)	**.590** (.360-1.11)	**1.29** (.710-3.37)	518
	01-02	*	< LOD	**.180** (.140-.220)	**.390** (.290-.550)	**.840** (.550-1.11)	700
Non-Hispanic whites	99-00	*	< LOD	**.280** (.250-.300)	**.550** (.450-.880)	**1.33** (.680-1.80)	591
	01-02	*	< LOD	**.240** (<LOD-.270)	**.450** (.390-.560)	**.840** (.580-1.14)	957

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

application median urinary levels of summed *cis*- and *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (Hardt and Angerer, 2003) were similar to the 95th percentiles for adults in the NHANES 2001-2002 subsample (CDC, 2005). The maximum post-application urinary levels, however, were up to 27 times higher than the 95th percentile for adults in the NHANES 2001-2002 subsample (CDC, 2005).

Finding a measurable amount of *cis*- or *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid in urine does not mean that the level causes an adverse health effect. Biomonitoring studies on urinary levels of *cis*- or *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of pyrethroid pesticides than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary *trans*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid

Metabolite of Cyfluthrin, trans-Cypermethrin, and trans-Permethrin

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**.560** (.480-.700)	**1.40** (1.17-1.77)	**3.42** (2.39-5.56)	1976
	01-02	*	**< LOD**	**.420** (<LOD-.570)	**1.20** (.910-1.77)	**2.54** (1.68-3.70)	2525
Age group							
6-11 years	99-00	*	**< LOD**	**.970** (.700-1.66)	**2.91** (1.76-4.19)	**4.19** (2.97-11.7)	478
	01-02	*	**< LOD**	**.470** (<LOD-.760)	**1.39** (1.03-1.68)	**2.50** (1.55-3.54)	576
12-19 years	99-00	*	**< LOD**	**.710** (.520-.860)	**2.07** (1.25-3.42)	**4.28** (2.12-6.23)	675
	01-02	*	**< LOD**	**.490** (<LOD-.670)	**1.20** (.800-1.60)	**2.01** (1.49-3.77)	826
20-59 years	99-00	*	**< LOD**	**.500** (.400-.620)	**1.17** (.910-1.68)	**2.94** (1.49-5.56)	823
	01-02	*	**< LOD**	**< LOD**	**1.17** (.850-1.85)	**2.56** (1.64-4.66)	1123
Gender							
Males	99-00	*	**< LOD**	**.560** (.500-.670)	**1.28** (1.11-1.63)	**2.25** (1.55-5.10)	961
	01-02	*	**< LOD**	**.410** (<LOD-.500)	**1.09** (.810-1.63)	**2.37** (1.55-4.48)	1184
Females	99-00	*	**< LOD**	**.550** (.410-.820)	**1.77** (1.07-3.08)	**4.19** (3.08-6.81)	1015
	01-02	*	**< LOD**	**.440** (<LOD-.660)	**1.26** (.920-1.95)	**2.56** (1.76-3.58)	1341
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**.470** (.410-.530)	**1.23** (.830-1.60)	**1.87** (1.49-3.35)	691
	01-02	*	**< LOD**	**.410** (<LOD-.520)	**.940** (.680-1.16)	**1.59** (1.11-2.01)	680
Non-Hispanic blacks	99-00	*	**< LOD**	**.780** (.490-1.13)	**1.84** (1.08-4.69)	**4.69** (1.41-14.5)	518
	01-02	*	**< LOD**	**.580** (.460-.750)	**1.27** (1.03-1.68)	**2.22** (1.68-2.95)	690
Non-Hispanic whites	99-00	*	**< LOD**	**.560** (.460-.730)	**1.41** (1.14-2.14)	**3.89** (2.14-6.43)	595
	01-02	*	**< LOD**	**.400** (<LOD-.610)	**1.20** (.840-1.90)	**2.62** (1.60-4.66)	954

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.4 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary *trans*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (creatinine corrected)

Metabolite of Cyfluthrin, trans-Cypermethrin, and trans-Permethrin

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**.700** (.610-.780)	**1.56** (1.33-1.87)	**2.65** (2.15-3.89)	1976
	01-02	*	**< LOD**	**.720** (<LOD-.780)	**1.45** (1.22-1.88)	**2.55** (2.15-3.10)	2524
Age group							
6-11 years	99-00	*	**< LOD**	**1.31** (.720-1.74)	**2.37** (1.56-5.07)	**5.60** (1.91-11.3)	478
	01-02	*	**< LOD**	**.900** (<LOD-1.13)	**2.16** (1.40-2.61)	**2.86** (2.34-3.44)	576
12-19 years	99-00	*	**< LOD**	**.530** (.440-.730)	**1.42** (.820-2.19)	**2.19** (1.34-4.31)	675
	01-02	*	**< LOD**	**.530** (<LOD-.660)	**.970** (.800-1.29)	**1.57** (1.07-2.60)	825
20-59 years	99-00	*	**< LOD**	**.700** (.570-.770)	**1.33** (1.12-1.87)	**2.39** (1.87-3.36)	823
	01-02	*	**< LOD**	**< LOD**	**1.47** (1.22-2.00)	**2.55** (2.07-3.11)	1123
Gender							
Males	99-00	*	**< LOD**	**.560** (.480-.670)	**1.26** (1.07-1.42)	**2.15** (1.47-2.74)	961
	01-02	*	**< LOD**	**.520** (<LOD-.580)	**1.08** (.880-1.35)	**2.20** (1.45-2.57)	1184
Females	99-00	*	**< LOD**	**.880** (.720-1.11)	**1.91** (1.48-2.39)	**3.67** (2.30-6.28)	1015
	01-02	*	**< LOD**	**.880** (<LOD-1.00)	**1.75** (1.47-2.15)	**2.81** (2.30-3.19)	1340
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**.580** (.500-.750)	**1.35** (1.02-1.65)	**2.00** (1.56-2.80)	691
	01-02	*	**< LOD**	**.570** (<LOD-.640)	**1.08** (.930-1.22)	**1.87** (1.27-2.15)	680
Non-Hispanic blacks	99-00	*	**< LOD**	**.570** (.470-.740)	**1.70** (.850-3.13)	**3.36** (1.87-8.91)	518
	01-02	*	**< LOD**	**.470** (.410-.540)	**1.12** (.800-1.41)	**1.98** (1.20-2.68)	689
Non-Hispanic whites	99-00	*	**< LOD**	**.760** (.700-.850)	**1.64** (1.33-2.00)	**3.31** (2.00-5.60)	595
	01-02	*	**< LOD**	**.780** (<LOD-.850)	**1.48** (1.27-2.07)	**2.55** (2.15-3.11)	954

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

References

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Deltamethrin

CAS No. 52918-63-5

General Information

Cis-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid is a metabolite of the pyrethroid insecticide deltamethrin. Outside the U.S., deltamethrin has been used against mosquitoes that carry malaria, in some situations replacing the use of DDT. Deltamethrin can degrade to *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid in the environment (IPCS, 1990). Thus, in detection of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid in the urine may reflect exposure to deltamethrin or to *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid formed in the environment.

Biomonitoring Information

Urinary levels of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid reflect recent exposure to deltamethrin or its environmental degradate. In the NHANES 2001-2002 subsample, urinary levels of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid were below the limit of detection (CDC, 2005). In an analysis of 217 urine specimens from a nonrandom sample of United States residents, Baker et al. (2004) reported a geometric mean concentration of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid of 0.39 µg/L. Studies in Germany of 396 children and adolescents (Becker et al., 2006) and 1177 urban adults and children (Heudorf et al., 2001) showed that urinary levels of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid at the 95th percentile ranged slightly higher (0.3-0.5 µg/L) than the detection limit (0.1 µg/L) for the NHANES 2001-2002 subsample (CDC, 2005). Urinary levels for adults and children in these studies were similar (Heudorf et al., 2001, 2006) and estimated daily intakes based on urinary levels in children were considered to be below acceptable daily intakes (Heudorf et al., 2004).

Following residential spraying with deltamethrin for malaria protection in Mexico, mean peak urinary levels of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid in children increased at least 450-fold relative to the non-detectable background levels for several days and mean levels remained slightly above background levels 45 days after the spraying (Ortiz-Perez et al., 2005). The peak mean levels in these children were more than 800-fold higher than the detection limit in the 2001-2002 NHANES subsample.

Finding a measurable amount of *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies provide physicians and public health officials with reference values so that they can determine whether other people have been exposed to higher levels of deltamethrin than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary *cis*-3-(2,2-Dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid

Metabolite of Deltamethrin

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1698
	01-02	*	< LOD	< LOD	< LOD	< LOD	2539
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	415
	01-02	*	< LOD	< LOD	< LOD	< LOD	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	570
	01-02	*	< LOD	< LOD	< LOD	< LOD	831
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	713
	01-02	*	< LOD	< LOD	< LOD	< LOD	1128
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	818
	01-02	*	< LOD	< LOD	< LOD	< LOD	1193
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	880
	01-02	*	< LOD	< LOD	< LOD	< LOD	1346
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	578
	01-02	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	445
	01-02	*	< LOD	< LOD	< LOD	< LOD	701
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	527
	01-02	*	< LOD	< LOD	< LOD	< LOD	957

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.1 and 0.1.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary *cis*-3-(2,2-Dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid (creatinine corrected)

Metabolite of Deltamethrin

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1698
	01-02	*	< LOD	< LOD	< LOD	< LOD	2538
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	415
	01-02	*	< LOD	< LOD	< LOD	< LOD	580
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	570
	01-02	*	< LOD	< LOD	< LOD	< LOD	830
20-59 years	99-00	*	< LOD	< LOD	< LOD	< LOD	713
	01-02	*	< LOD	< LOD	< LOD	< LOD	1128
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	818
	01-02	*	< LOD	< LOD	< LOD	< LOD	1193
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	880
	01-02	*	< LOD	< LOD	< LOD	< LOD	1345
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	578
	01-02	*	< LOD	< LOD	< LOD	< LOD	680
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	445
	01-02	*	< LOD	< LOD	< LOD	< LOD	700
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	527
	01-02	*	< LOD	< LOD	< LOD	< LOD	957

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Becker K, Seiwert M, Angerer J, Kolossa-Gehring M, Hoppe HW, Ball M, et al. GerES IV pilot study: assessment of the exposure of German children to organophosphorus and pyrethroid pesticides. Int J Hyg Environ Health 2006;209(3):221-233.

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Cyhalothrin
CAS No. 68359-37-5

Cypermethrin
CAS No.52315-07-8

Deltamethrin
CAS No. 52918-63-5

Fenpropathrin
CAS No. 39515-41-8

Permethrin
CAS No. 52645-53-1

Tralomethrin
CAS No. 66841-25-6

General Information

The chemical 3-phenoxybenzoic acid is a metabolite and an environmental degradate of the six pyrethroid pesticides listed above. Thus, the presence of 3-phenoxybenzoic acid in urine not only reflects the metabolic transformation of any of the six pesticides listed above, but can reflect direct exposure to 3-phenoxybenzoic acid formed in the environment from the degradation of these pesticides.

Biomonitoring Information

Urinary levels of 3-phenoxybenzoic acid reflect recent exposure to the parent pyrethroid pesticides. In an analysis of 217 urine specimens from a nonrandom sample of United States residents, Baker et al. (2004) reported geometric mean levels of 3-phenoxybenzoic acid that were approximately sixfold higher than levels for adults in the NHANES 2001-2002 subsample (CDC, 2005). Median levels of urinary 3-phenoxybenzoic acid were 67-fold higher in 307 pregnant New York City women who used indoor pesticides compared with the median levels for adults in the NHANES 2001-2002 subsample (Berkowitz et al., 2003; CDC, 2005). In the New York City study, a temporal variation in levels was observed and considered to correspond to seasonal spraying of pesticides. A study of 396 German children (Becker et al., 2006) showed that urinary levels of 3-phenoxybenzoic acid at the 95th percentile were similar to levels at the 95th percentile for children in the U.S. representative NHANES 2001-2002 subsample (CDC, 2005). Urinary levels of 3-phenoxybenzoic acid in children were found to be related to residential pesticide use and house dust levels (Lu et al., 2006; Becker et al., 2006). A small sample of occupationally unexposed Italian residents had median levels of urinary 3-phenoxybenzoic acid that were about fourfold higher than for adults in the NHANES 2001-2002 subsample (CDC, 2005; Saieva et al., 2004). In one study of 145 urban residents in 80 private homes in Germany, urinary 3-phenoxybenzoic acid levels at the 95th percentile were about threefold lower than the levels at the 95th percentile in the 2001-2002 NHANES subsample (Berger-Preiss et al., 2002; CDC, 2005).

In 57 volunteers entering areas previously spot-sprayed with various pyrethroid pesticides, median urinary levels of 3-phenoxybenzoic acid were slightly less than median levels in the NHANES 2001-2002 subsample (Leng et al., 2003; CDC, 2005). Following residential spraying with deltamethrin for malaria protection in Mexico, mean peak urinary levels of 3-phenoxybenzoic acid in children increased at least sixtyfold over non-detectable background levels for several days and mean levels remained slightly above background levels 45 days after the spraying (Ortiz-Perez et al., 2005). The mean peak levels in these children were 83-fold higher than the geometric mean for children in the NHANES 2001-2002 subsample (CDC, 2005). In a small group of indoor pest-control operators, the post-application median urinary levels of 3-phenoxybenzoic acid were 24-fold higher than those for adults in the NHANES 2001-2002 subsample (CDC, 2005; Hardt and Angerer, 2003).

Finding a measurable amount in urine does not mean that the level will result in an adverse health effect. Biomonitoring studies of 3-phenoxybenzoic acid provide physicians and public health officials with reference values so that they can determine whether other people have been exposed to higher levels of pyrethroids than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 3-Phenoxybenzoic acid

Metabolite of Cypermethrin, Deltamethrin, and Permethrin

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.292** (.247-.345)	**.250** (.190-.320)	**.730** (.590-.850)	**1.75** (1.49-2.16)	**4.33** (2.62-6.30)	1998
	01-02	**.321** (.276-.374)	**.280** (.230-.340)	**.700** (.560-.830)	**1.69** (1.41-2.33)	**3.32** (2.52-5.25)	2539
Age group							
6-11 years	99-00	**.417** (.292-.595)	**.320** (.210-.490)	**1.12** (.700-1.60)	**4.18** (2.02-6.54)	**8.63** (3.89-71.1)	483
	01-02	**.325** (.260-.406)	**.300** (.200-.420)	**.760** (.570-1.05)	**1.81** (1.42-2.78)	**3.38** (2.25-4.12)	580
12-19 years	99-00	**.336** (.265-.427)	**.290** (.200-.440)	**.870** (.620-1.04)	**1.93** (1.49-2.90)	**4.33** (1.83-11.1)	682
	01-02	**.353** (.288-.434)	**.300** (.250-.390)	**.800** (.560-1.13)	**1.86** (1.48-2.35)	**3.45** (2.14-6.69)	831
20-59 years	99-00	**.267** (.227-.314)	**.230** (.160-.300)	**.640** (.510-.820)	**1.49** (1.25-1.78)	**3.21** (2.04-5.41)	833
	01-02	**.314** (.271-.364)	**.270** (.220-.340)	**.670** (.530-.780)	**1.65** (1.27-2.34)	**3.25** (2.51-6.16)	1128
Gender							
Males	99-00	**.273** (.226-.330)	**.250** (.180-.330)	**.710** (.570-.820)	**1.49** (1.29-1.73)	**2.41** (1.92-3.79)	974
	01-02	**.328** (.277-.387)	**.300** (.230-.370)	**.680** (.560-.750)	**1.55** (1.26-2.35)	**3.23** (2.56-5.78)	1193
Females	99-00	**.311** (.253-.384)	**.250** (.190-.340)	**.740** (.510-.990)	**2.30** (1.63-3.36)	**6.03** (3.27-11.8)	1024
	01-02	**.315** (.266-.373)	**.260** (.210-.320)	**.740** (.550-.940)	**1.76** (1.48-2.39)	**3.38** (2.34-6.16)	1346
Race/ethnicity							
Mexican Americans	99-00	**.260** (.230-.295)	**.230** (.190-.270)	**.600** (.430-.750)	**1.35** (1.16-1.53)	**2.18** (1.53-3.26)	697
	01-02	**.297** (.238-.369)	**.260** (.200-.360)	**.650** (.490-.810)	**1.30** (.830-2.26)	**2.71** (1.51-3.44)	680
Non-Hispanic blacks	99-00	**.454** (.352-.586)	**.450** (.350-.610)	**1.13** (.750-1.46)	**2.32** (1.45-5.35)	**5.35** (2.32-21.1)	524
	01-02	**.507** (.428-.601)	**.520** (.430-.630)	**.960** (.840-1.12)	**2.01** (1.65-2.28)	**3.25** (2.52-4.62)	701
Non-Hispanic whites	99-00	**.288** (.233-.355)	**.240** (.160-.320)	**.710** (.530-.850)	**1.78** (1.41-3.05)	**5.34** (2.62-8.43)	603
	01-02	**.298** (.246-.362)	**.240** (.190-.320)	**.590** (.470-.800)	**1.72** (1.27-2.46)	**3.50** (2.25-7.64)	957

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.1 and 0.1.

Urinary 3-Phenoxybenzoic acid (creatinine corrected)

Metabolite of Cypermethrin, Deltamethrin, and Permethrin

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.261** (.224-.304)	**.250** (.200-.280)	**.550** (.460-.630)	**1.40** (1.13-1.73)	**3.19** (2.16-4.55)	1998
	01-02	**.316** (.274-.365)	**.280** (.240-.330)	**.580** (.490-.720)	**1.48** (1.13-1.91)	**3.10** (2.21-4.88)	2538
Age group							
6-11 years	99-00	**.450** (.299-.677)	**.370** (.240-.590)	**1.13** (.730-1.62)	**3.96** (1.75-8.07)	**9.91** (2.43-64.0)	483
	01-02	**.423** (.335-.534)	**.380** (.300-.500)	**.860** (.590-1.35)	**2.21** (1.61-2.95)	**3.32** (2.64-5.40)	580
12-19 years	99-00	**.227** (.178-.290)	**.210** (.160-.270)	**.490** (.380-.730)	**1.37** (1.03-1.62)	**2.52** (1.41-4.44)	682
	01-02	**.274** (.229-.328)	**.240** (.190-.310)	**.540** (.420-.730)	**1.11** (.860-1.63)	**2.35** (1.36-6.19)	830
20-59 years	99-00	**.246** (.216-.278)	**.240** (.200-.270)	**.510** (.400-.590)	**1.11** (.860-1.49)	**2.53** (1.73-4.09)	833
	01-02	**.311** (.271-.357)	**.280** (.240-.330)	**.550** (.440-.670)	**1.44** (1.02-1.91)	**3.22** (1.91-4.92)	1128
Gender							
Males	99-00	**.210** (.173-.253)	**.190** (.150-.250)	**.510** (.390-.580)	**1.09** (.840-1.41)	**1.72** (1.49-2.52)	974
	01-02	**.264** (.226-.309)	**.240** (.200-.280)	**.490** (.410-.570)	**1.17** (.960-1.60)	**2.81** (1.60-4.00)	1193
Females	99-00	**.323** (.270-.387)	**.270** (.240-.330)	**.610** (.480-.740)	**1.94** (1.35-3.00)	**5.04** (3.19-6.90)	1024
	01-02	**.378** (.321-.446)	**.330** (.290-.400)	**.720** (.530-.930)	**1.67** (1.25-2.37)	**3.43** (2.25-5.19)	1345
Race/ethnicity							
Mexican Americans	99-00	**.234** (.202-.272)	**.220** (.190-.230)	**.480** (.370-.590)	**1.04** (.700-1.39)	**1.67** (1.06-3.00)	697
	01-02	**.275** (.230-.329)	**.240** (.210-.320)	**.510** (.400-.650)	**1.03** (.750-1.67)	**1.83** (1.15-2.74)	680
Non-Hispanic blacks	99-00	**.309** (.238-.401)	**.270** (.220-.350)	**.640** (.460-.930)	**1.49** (1.05-3.43)	**3.86** (1.51-7.25)	524
	01-02	**.362** (.300-.437)	**.350** (.280-.410)	**.640** (.530-.760)	**1.36** (1.17-1.83)	**2.84** (1.63-3.80)	700
Non-Hispanic whites	99-00	**.272** (.225-.329)	**.250** (.200-.290)	**.550** (.440-.670)	**1.55** (1.09-2.27)	**4.02** (2.07-5.49)	603
	01-02	**.312** (.261-.372)	**.280** (.230-.330)	**.560** (.440-.810)	**1.54** (1.09-2.35)	**3.43** (1.88-5.48)	957

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Antimony

CAS No. 7440-36-0

General Information

Antimony is found in ores or other minerals, often combined with oxygen to form antimony trioxide or with sulfur to form stibnite. Antimony can exist in one of four valences in its various chemical and physical forms: -3, 0, +3, and +5. It is used in metal alloys, storage batteries, solder, sheet and pipe metal, ammunition, metal bearings, castings, and pewter. It is also used in paints, ceramics, fireworks, enamels, and glass, and as a fire-retardant in textiles and plastics. Stibine is a metal hydride form of antimony used in the semiconductor industry. Two antimony compounds (sodium stibogluconate and antimony potassium tartrate) have been used as antiparasitic medications.

Antimony enters the environment from natural sources and from its use in industry. People are exposed to antimony primarily through food and, to a lesser extent, from air and drinking water. Workplace exposures can occur at smelters, coal-fired plants, and refuse incinerators that process or release antimony. Dermal contact with soil, water, or other substances containing antimony is another means of exposure. The absorption, distribution, and excretion of antimony vary depending on its oxidation state. Urinary excretion appears to be greater for pentavalent antimony

Urinary Antimony

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.132** (.120-.145)	**.130** (.120-.150)	**.220** (.200-.230)	**.330** (.300-.350)	**.430** (.390-.470)	2276
	01-02	**.134** (.126-.142)	**.130** (.130-.140)	**.190** (.180-.200)	**.270** (.250-.310)	**.350** (.320-.400)	2690
	03-04	*	**.080** (<LOD-.090)	**.130** (.120-.150)	**.200** (.190-.220)	**.280** (.250-.320)	2558
Age group							
6-11 years	99-00	**.176** (.154-.200)	**.190** (.160-.210)	**.260** (.230-.280)	**.350** (.300-.400)	**.440** (.320-.600)	316
	01-02	**.146** (.134-.160)	**.150** (.130-.160)	**.200** (.180-.210)	**.270** (.240-.330)	**.340** (.280-.440)	368
	03-04	**.099** (.087-.114)	**.100** (.070-.120)	**.160** (.120-.200)	**.240** (.190-.310)	**.310** (.230-.330)	290
12-19 years	99-00	**.158** (.141-.178)	**.170** (.150-.180)	**.240** (.210-.270)	**.350** (.290-.420)	**.460** (.350-.510)	663
	01-02	**.169** (.156-.184)	**.160** (.150-.180)	**.240** (.220-.260)	**.350** (.320-.410)	**.460** (.400-.500)	762
	03-04	**.105** (.095-.115)	**.100** (.090-.120)	**.150** (.140-.160)	**.230** (.200-.270)	**.290** (.250-.370)	725
20 years and older	99-00	**.123** (.112-.137)	**.120** (.110-.130)	**.200** (.180-.220)	**.310** (.290-.350)	**.430** (.390-.470)	1297
	01-02	**.128** (.119-.136)	**.130** (.120-.130)	**.180** (.170-.190)	**.250** (.220-.300)	**.330** (.280-.390)	1560
	03-04	*	**.070** (<LOD-.080)	**.120** (.100-.140)	**.190** (.170-.210)	**.270** (.220-.320)	1543
Gender							
Males	99-00	**.143** (.131-.157)	**.150** (.130-.160)	**.240** (.220-.260)	**.350** (.330-.390)	**.470** (.390-.570)	1132
	01-02	**.145** (.136-.154)	**.140** (.130-.150)	**.200** (.190-.210)	**.310** (.280-.330)	**.390** (.350-.440)	1335
	03-04	**.095** (.088-.103)	**.090** (.080-.100)	**.140** (.130-.160)	**.220** (.200-.250)	**.320** (.270-.350)	1281
Females	99-00	**.122** (.109-.137)	**.120** (.110-.140)	**.200** (.180-.220)	**.300** (.280-.340)	**.400** (.350-.460)	1144
	01-02	**.125** (.117-.133)	**.120** (.120-.130)	**.180** (.160-.190)	**.240** (.220-.280)	**.320** (.260-.360)	1355
	03-04	*	**< LOD**	**.120** (.090-.140)	**.180** (.150-.220)	**.230** (.190-.330)	1277
Race/ethnicity							
Mexican Americans	99-00	**.132** (.108-.161)	**.140** (.120-.170)	**.210** (.180-.240)	**.300** (.260-.390)	**.430** (.330-.560)	787
	01-02	**.142** (.130-.154)	**.130** (.130-.150)	**.200** (.170-.230)	**.260** (.240-.320)	**.360** (.300-.400)	683
	03-04	**.093** (.079-.110)	**.090** (<LOD-.120)	**.140** (.120-.160)	**.190** (.160-.260)	**.270** (.210-.330)	618
Non-Hispanic blacks	99-00	**.175** (.148-.207)	**.180** (.150-.200)	**.260** (.230-.300)	**.400** (.310-.490)	**.490** (.410-.710)	554
	01-02	**.180** (.164-.197)	**.170** (.160-.190)	**.250** (.220-.280)	**.360** (.320-.410)	**.460** (.370-.530)	667
	03-04	**.108** (.098-.119)	**.110** (.100-.120)	**.160** (.150-.190)	**.230** (.200-.280)	**.310** (.250-.360)	723
Non-Hispanic whites	99-00	**.128** (.115-.144)	**.130** (.110-.140)	**.210** (.190-.230)	**.330** (.280-.350)	**.400** (.360-.500)	768
	01-02	**.126** (.117-.135)	**.130** (.120-.130)	**.180** (.170-.190)	**.250** (.230-.300)	**.340** (.310-.390)	1132
	03-04	*	**.070** (<LOD-.080)	**.130** (.110-.140)	**.190** (.170-.210)	**.280** (.230-.320)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.04, 0.04, and 0.07, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

than for trivalent compounds (Elinder and Friberg, 1986). An elimination half-life of approximately 95 hours has been estimated after occupational exposures (Kentner et al., 1995).

Human health effects from antimony at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Inorganic antimony salts irritate the mucous membranes, skin, and eyes. Acute inhalation of antimony has been associated with irritation of the respiratory tract and impaired pulmonary function (Renes, 1953). Pulmonary edema may occur in severe cases of inhalation exposure (Cordasco et al., 1973). Dysrhythmias and T-wave changes on electrocardiogram have also been noted after both therapeutic (Berman, 1988; Ming-Hsin et al., 1958) and occupational exposures (Briegner et al., 1954). Histopathologic inflammatory and degenerative changes in the lung, myocardium, liver, and kidney have been demonstrated in high dose animal studies depending on the dose, species, and route of exposure (Elinder and Friberg, 1986). Acute antimony poisoning may cause a metallic taste, and gastrointestinal symptoms such as vomiting, diarrhea, abdominal pain, and ulcers (Werrin, 1962). The toxicity of stibine after acute inhalational exposure is similar to that of arsine, resulting in hemolysis with abdominal and back pain (Dernehl et al., 1944).

Workplace standards and recommendations for air exposure

Urinary Antimony (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.124** (.108-.143)	**.119** (.102-.143)	**.185** (.164-.214)	**.276** (.233-.333)	**.385** (.333-.430)	2276
	01-02	**.126** (.119-.134)	**.120** (.115-.126)	**.173** (.162-.188)	**.267** (.242-.300)	**.364** (.320-.414)	2689
	03-04	*	**.080** (<LOD-.086)	**.135** (.119-.143)	**.208** (.192-.230)	**.277** (.250-.294)	2558
Age group							
6-11 years	99-00	**.191** (.147-.248)	**.185** (.156-.220)	**.250** (.200-.417)	**.447** (.271-.741)	**.741** (.333-1.30)	316
	01-02	**.178** (.159-.200)	**.173** (.150-.193)	**.228** (.200-.272)	**.338** (.265-.480)	**.471** (.313-.727)	368
	03-04	**.116** (.103-.130)	**.118** (.098-.136)	**.167** (.146-.187)	**.256** (.194-.317)	**.333** (.250-.500)	290
12-19 years	99-00	**.121** (.104-.140)	**.120** (.095-.146)	**.176** (.146-.207)	**.259** (.206-.310)	**.310** (.228-.421)	663
	01-02	**.121** (.112-.131)	**.115** (.106-.127)	**.160** (.138-.186)	**.224** (.199-.245)	**.266** (.244-.310)	762
	03-04	**.075** (.068-.082)	**.068** (.061-.077)	**.100** (.092-.113)	**.156** (.126-.173)	**.193** (.172-.255)	725
20 years and older	99-00	**.118** (.104-.135)	**.111** (.097-.135)	**.175** (.149-.209)	**.263** (.227-.320)	**.352** (.320-.391)	1297
	01-02	**.122** (.115-.129)	**.115** (.108-.121)	**.167** (.153-.181)	**.265** (.241-.300)	**.364** (.318-.405)	1559
	03-04	*	**.079** (<LOD-.087)	**.135** (.116-.145)	**.209** (.195-.233)	**.278** (.250-.294)	1543
Gender							
Males	99-00	**.112** (.099-.127)	**.109** (.095-.127)	**.164** (.146-.181)	**.226** (.204-.268)	**.320** (.235-.391)	1132
	01-02	**.114** (.107-.123)	**.108** (.103-.115)	**.153** (.138-.171)	**.228** (.205-.250)	**.333** (.281-.438)	1334
	03-04	**.080** (.076-.084)	**.075** (.069-.081)	**.122** (.111-.132)	**.192** (.173-.209)	**.253** (.230-.278)	1281
Females	99-00	**.137** (.117-.161)	**.131** (.108-.164)	**.213** (.176-.247)	**.320** (.263-.417)	**.429** (.357-.485)	1144
	01-02	**.139** (.131-.148)	**.132** (.124-.140)	**.196** (.178-.211)	**.295** (.267-.317)	**.371** (.333-.444)	1355
	03-04	*	**< LOD**	**.143** (.125-.161)	**.225** (.188-.261)	**.288** (.250-.333)	1277
Race/ethnicity							
Mexican Americans	99-00	**.120** (.107-.135)	**.114** (.105-.129)	**.167** (.148-.203)	**.250** (.209-.315)	**.333** (.280-.357)	787
	01-02	**.138** (.128-.149)	**.130** (.117-.143)	**.182** (.159-.203)	**.269** (.229-.308)	**.338** (.308-.429)	682
	03-04	**.086** (.076-.098)	**.082** (<LOD-.092)	**.129** (.107-.151)	**.189** (.154-.238)	**.238** (.185-.321)	618
Non-Hispanic blacks	99-00	**.114** (.099-.133)	**.112** (.098-.130)	**.163** (.144-.183)	**.236** (.195-.338)	**.343** (.255-.425)	554
	01-02	**.123** (.113-.134)	**.115** (.106-.127)	**.163** (.150-.181)	**.233** (.208-.267)	**.300** (.248-.373)	667
	03-04	**.078** (.071-.085)	**.074** (.069-.082)	**.109** (.096-.124)	**.170** (.148-.192)	**.222** (.179-.257)	723
Non-Hispanic whites	99-00	**.129** (.109-.152)	**.125** (.102-.152)	**.195** (.167-.225)	**.298** (.239-.352)	**.400** (.333-.444)	768
	01-02	**.127** (.117-.138)	**.120** (.113-.130)	**.176** (.159-.198)	**.280** (.241-.317)	**.380** (.318-.471)	1132
	03-04	*	**.081** (<LOD-.089)	**.139** (.124-.147)	**.217** (.200-.238)	**.286** (.253-.333)	1074

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

to antimony have been established by OSHA and ACGIH, respectively, and a drinking water standard has been established by the U.S. EPA. Antimony trioxide is rated by IARC as a possible human carcinogen. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of urinary antimony reflect recent exposure. Earlier measurements in general populations (Minoia et al., 1990; Paschal et al., 1998) or compiled reference ranges (Hamilton et al., 1994) have reported values slightly higher than those in this *Report*, which may be due to methodologic, population, or exposure differences. Levels of urinary antimony in infants appeared to be similar to those reported by CDC (2005) for young children (Cullen et al., 1998; Dezateux et al., 1997). Urinary antimony was not associated with locally elevated soil levels in a study of more than 200 German residents (Gebel et al., 1998). Several investigations of airborne antimony exposures in workers have found urinary levels that are many times higher than those seen in NHANES 1999-2000, 2001-2002, and 2003-2004, even when exposure levels were below workplace air standards (Bailly et al., 1991; Iavicoli et al., 2002; Kentner et al., 1995; Liao Y-H et al., 2004; Ludersdorf et al., 1987).

Finding a measurable amount of antimony in urine does not mean that the level of antimony causes an adverse health effect. Biomonitoring studies on levels of urinary antimony can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of antimony than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Arsenic

CAS No. 7440-38-2

General Information

Arsenic is an element that is widely distributed in the earth's surface in small amounts. In nature, it is found in over 200 crystalline or mineral forms, such as arsenopyrite (FeAsS) and realgar (As_4S_4), or rarely as elemental metalloids (yellow, black, and gray forms). Arsenic can combine with such non-carbon chemicals as sulfur and oxygen to form arsenides, arsenites, and arsenates (oxidation states of -3, +3 and +5), referred to as inorganic arsenic compounds. Arsenic trioxide (As_2O_3, a trivalent compound known as white arsenic) is a common natural and commercial form that can be released into the air during volcanic action; the smelting of copper, lead, and other metals; and, to a lesser extent, from coal burning. The United States no longer produces arsenic from mining but imports about 22,000 metric tons annually, mostly for use in wood preservation (ATSDR, 2005). Various forms of inorganic arsenic can occur in groundwater from natural sources or as a result of soil application or industrial waste. Arsenic can also combine with organic substances in nature to form such organic arsenic compounds as arsenobetaine, arsenocholine, trimethylarsine oxide, and arsenosugars. Arsine (AsH_3) is a reactive, gaseous hydride manufactured in small quantities for use in the semiconductor industry.

Arsenic and its compounds have had many uses in the past and present as medicines, pesticides, alloys, semiconductors, and as homicidal poisons. Before the 20th century, arsenic compounds, particularly arsenic trioxide, were used as treatments for syphilis, psoriasis, cancers, mental disorders, and as a cosmetic to lighten complexion. Various arsenic compounds were used in paint pigments and for tanning animal hides. In the last century, lead hydrogen arsenate, copper arsenates, sodium arsenite, cacodylic acid, and monosodium methyl arsenate were used as pesticides but contemporary uses are restricted. Roxarsone and other organic arsenicals are anticoccidial agents added to poultry feed. Since the 1940s, chromated copper arsenate (CCA) has been used to treat outdoor timbers and pressure-treated woods to prevent wood rot. Although it is still widely used in the United States, CCA-treated wood has been restricted since 2003 and no longer can be used in residential applications such as decks, retaining walls, and play sets. Arsenic trioxide is approved to treat acute promyelocytic leukemia. Gallium, aluminum, and indium arsenides are used in the semiconductor industry. Also, arsenic as elemental metalloids may be used in some ammunition, solders, as alloy in metal bearings, and in lead-acid storage battery grids.

General population exposure to inorganic arsenic can occur through consumption of drinking water and, to a lesser extent, meats, grain, and produce. Arsenic is measurable in most soils, ocean and fresh waters, and foods. Water sources contain mostly inorganic arsenate, though in some locations arsenite may be prevalent (WHO, 2001). Groundwater

Urinary Total Arsenic

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**8.30** (7.19-9.57)	**7.70** (6.90-8.90)	**16.0** (14.1-18.7)	**37.4** (31.6-43.5)	**65.4** (48.7-83.3)	2557
Age group							
6-11 years	03-04	**7.08** (5.66-8.84)	**6.80** (5.90-7.70)	**10.9** (8.90-14.2)	**24.6** (13.8-61.8)	**46.9** (17.5-178)	290
12-19 years	03-04	**8.55** (7.34-9.97)	**8.10** (6.80-9.40)	**15.2** (12.2-17.8)	**30.5** (23.1-40.4)	**46.1** (32.9-62.5)	725
20 years and older	03-04	**8.41** (7.25-9.77)	**7.90** (7.00-9.10)	**17.0** (15.0-19.7)	**40.5** (34.9-46.2)	**66.2** (51.2-93.1)	1542
Gender							
Males	03-04	**9.50** (8.34-10.8)	**8.90** (7.70-9.80)	**17.6** (15.2-20.1)	**41.6** (32.5-52.8)	**65.8** (48.7-95.4)	1281
Females	03-04	**7.30** (6.02-8.84)	**6.90** (5.90-8.30)	**15.0** (11.3-19.5)	**33.4** (26.5-41.7)	**60.5** (40.8-77.1)	1276
Race/ethnicity							
Mexican Americans	03-04	**9.29** (8.12-10.6)	**9.20** (8.10-10.3)	**16.2** (13.5-19.9)	**34.4** (24.0-60.5)	**68.2** (41.3-111)	618
Non-Hispanic blacks	03-04	**11.6** (9.50-14.1)	**10.4** (7.90-11.8)	**21.5** (14.9-34.4)	**43.5** (36.2-61.8)	**78.0** (43.6-141)	722
Non-Hispanic whites	03-04	**7.12** (6.13-8.27)	**7.00** (6.10-7.90)	**13.7** (11.3-15.8)	**29.0** (22.6-35.9)	**53.1** (38.4-65.6)	1074

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.74.

sources of drinking water often have measurable arsenic and several regions of the United States have naturally higher arsenic levels than the U.S. EPA's maximum contaminant level (Hughes, 2006; U.S. EPA, 2001). Extremely high groundwater arsenic levels, as observed in Bangladesh where millions of people have been exposed, have caused clinical arsenic poisoning. Though modest bioconcentration occurs in some aquatic life, arsenic does not show biomagnification in the food chain (WHO, 2001). Children may have additional exposures from ingestion of contaminated soils (e.g., mine tailings), dust, and contact with CCA-preserved wood structures. Smelter workers can have significant inhalational exposures to airborne arsenic trioxide for which air standards have been established. Smoking tobacco is also a source of inorganic arsenic. The semiconductor dopants, gallium arsenide and indium arsenide, are used in enclosed ultraclean operations within the semiconductor industry, so exposure to the general population is extremely limited.

Inorganic arsenic is well absorbed from the gastrointestinal tract and absorbed to a lesser degree through inhalation, but is poorly absorbed dermally (WHO, 2001). After absorption, inorganic arsenic is widely distributed within the body. Arsenate is reduced in the body to arsenite (oxidation state +3), though some reduction may occur in the gut prior to absorption. Arsenite is then oxidatively methylated to the monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) with subsequent excretion primarily in the urine (NRC, 2001). Inorganic arsenic and its metabolites have elimination half-lives of approximately 2–4 days (Lauwerys and Hoet, 2001; NRC, 2001). Some studies suggest that variation in the degree of methylation among persons is related to the susceptibility of arsenic-induced disease and may involve consideration of genetic polymorphisms, dose level, age, selenium, and folate status (Chen et al., 2007; Chowdhury et al., 2003; Gamble et al., 2006; Steinmaus et al., 2007; Tseng, 2007; WHO, 2001). Direct exposure to DMA and MMA may result from use of the two pesticides, cacodylic acid and monosodium methyl arsenate.

Fish, shellfish, kelp, and some other seafood can contain organic forms of arsenic including arsenobetaine, arsenocholine, trimethylarsine oxide (TMAO), and arsenosugars. In aquatic organisms, arsenocholine is converted to arsenobetaine and also to small amounts of TMAO (Christakopoulos et al., 1988). TMAO is also formed in the environment from microbiological action and is a metabolite of arsenic in certain mammals. In aquatic sediments, organic arsenic can be converted back to methylated and inorganic arsenic. Ingestion of arsenosugars in kelp and algae can also lead to the excretion of DMA. These organic forms of arsenic from seafood are absorbed and quickly excreted in the urine (WHO, 2001).

Inorganic forms of arsenic demonstrate high acute toxicity, with trivalent inorganic arsenic (arsenite) being more toxic than pentavalent inorganic arsenic (arsenate) (NRC, 2001, WHO, 2001). The reduced form of MMA (oxidation state

Urinary Total Arsenic (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**8.24** (7.07-9.59)	**7.04** (5.93-8.51)	**14.1** (11.6-17.2)	**30.4** (26.0-38.7)	**50.4** (40.3-64.5)	2557
Age group							
6-11 years	03-04	**8.25** (6.58-10.3)	**7.18** (5.93-9.45)	**11.7** (9.10-16.3)	**22.2** (12.0-69.5)	**40.1** (14.7-188)	290
12-19 years	03-04	**6.11** (5.23-7.13)	**5.06** (4.47-6.04)	**9.66** (7.44-11.2)	**17.8** (12.0-26.0)	**27.8** (20.7-35.9)	725
20 years and older	03-04	**8.64** (7.38-10.1)	**7.47** (6.20-9.01)	**15.4** (12.7-18.8)	**33.8** (27.3-41.2)	**53.9** (45.4-64.5)	1542
Gender							
Males	03-04	**8.00** (6.81-9.40)	**6.75** (5.66-8.35)	**13.7** (11.0-18.0)	**28.7** (25.1-36.4)	**45.6** (35.3-62.1)	1281
Females	03-04	**8.47** (7.12-10.1)	**7.33** (6.10-8.75)	**14.4** (11.7-17.7)	**32.3** (24.2-46.6)	**58.4** (42.8-75.0)	1276
Race/ethnicity							
Mexican Americans	03-04	**8.61** (7.33-10.1)	**7.76** (6.30-9.44)	**12.6** (10.2-15.9)	**24.0** (17.7-34.8)	**42.4** (24.8-62.4)	618
Non-Hispanic blacks	03-04	**8.31** (6.99-9.88)	**6.88** (5.66-8.41)	**13.8** (11.5-17.0)	**27.6** (17.9-56.0)	**54.3** (27.5-120)	722
Non-Hispanic whites	03-04	**7.50** (6.25-9.01)	**6.32** (5.28-7.96)	**12.5** (9.86-17.1)	**26.8** (21.8-32.0)	**40.0** (31.3-53.9)	1074

+3) shows greater toxicity than arsenite itself (Aposhian et al., 2000; Bredfeldt et al., 2006; Cohen et al., 2006) and newly discovered thioarsenic metabolites may also be as toxic (Naranmandura et al., 2007; Raml et al., 2007). Arsenic has many actions demonstrated in cellular studies, including inhibition of numerous enzymes, substitution in phosphate metabolism, interference in signal transduction pathways, and altered gene expression. Such actions may lead to decreased energy production, increased oxidative stress, apoptosis, cytotoxicity, and endothelial injury (Kumagai and Sumi, 2007; NRC; 2001). Acutely, arsenite will inhibit cellular pyruvate dehydrogenase by binding to the sulfhydryl groups of dihydrolipoamide, and it also will inhibit succinate dehydrogenase, leading to a decrease in adenosine triphosphate energy production. Cellular glucose uptake, gluconeogenesis, fatty acid oxidation, and production of glutathione may be affected as well. Although arsenate is reduced in the body to arsenite, it may have its own separate toxic action by substituting for phosphate in glycolysis and other pathways, and by uncoupling oxidative phosphorylation (NRC, 2001; WHO, 2001).

Acute toxicity resulting from the ingestion of large amounts of trivalent arsenic (e.g., arsenic trioxide) includes hemorrhagic gastritis with nausea, vomiting, and diarrhea, which can lead to dehydration and shock. Cardiac arrhythmias, hepatotoxicity, renal failure, and peripheral neuropathy may also occur with large doses or after surviving an acute overdose. Chronic human intake of arsenic at less than acutely toxic doses, including drinking water sources with elevated arsenic levels (e.g., Bangladesh, Taiwan, Chile), can cause peripheral sensorimotor neuropathies, peripheral vascular disease, noncirrhotic portal hypertension, hematocytopenias, hyperkeratosis, and hyperpigmentation of the skin (NRC, 2001; WHO, 2001). With chronic exposure, some of these effects may take years to develop. Chronic elevated arsenic intakes have been associated with diabetes, hypertension, and childhood neurodevelopmental effects in observational human studies, but additional or confirmatory research is needed (Kapaj et al., 2006; WHO, 2001). The organic forms of arsenic occurring in seafood have little known toxicity. Acute unintentional inhalation of arsine gas can produce hemolysis of red blood cells.

Chronic arsenic exposure in humans is considered to be a cause of skin, lung, and bladder cancer (IARC, 2004; NRC, 2001). The risk of lung cancer appears more pronounced when large environmental exposures start in childhood (Smith et al., 2006) or when exposure occurs in smokers (Chen et al., 2004). Studies of arsenic at levels typical of U.S. drinking water have not been associated with increased cancer rates (Schoen et al., 2004). Laboratory studies using inorganic arsenic have shown chromosomal aberrations, cell transformations, and DNA repair inhibition (Cohen et al., 2006; U.S.EPA, 1998; WHO, 2001). OSHA and ACGIH have established workplace standards and guidelines for arsenic exposure and monitoring, respectively. The U.S.EPA has established drinking water, food residue, and environmental standards for arsenic and arsenic

Urinary Arsenic (V) Acid

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	**1.10** (<LOD-1.50)	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	**1.10** (<LOD-1.30)	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-1.60)	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	**1.10** (<LOD-1.50)	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-1.50)	1284
Females	03-04	*	< LOD	< LOD	< LOD	**1.10** (<LOD-1.30)	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-1.60)	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-1.80)	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	**1.10** (<LOD-1.50)	1078

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.0.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

compounds, and the FDA has established a bottled drinking water standard. IARC and NTP recognize inorganic arsenic and arsenic compounds as human carcinogens. DMA produced bladder cancer in some chronic rat studies (Cohen et al., 2006). In animal studies, arsenic has been fetotoxic and teratogenic, but generally only at maternally toxic doses (WHO, 2001). Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Urinary arsenic levels reflect recent exposures and are moderately to highly correlated with arsenic intakes from drinking water and dietary sources (Ahsan et al., 2000; Calderon et al., 1999; Pellizzari and Clayton, 2006; WHO, 2001). Daily variation in creatinine-corrected urinary arsenic is relatively small when intake is constant (Calderon et al., 1999). Urinary arsenic levels were a better predictor for risk of arsenical skin lesions than were arsenic levels in drinking water in Bangladesh (Ahsan et al., 2000). Consequently, urinary arsenic levels have been accepted as a good biomarker of dose (WHO, 2001). Several studies have shown that urinary arsenic levels are not correlated with low levels of arsenic measured in house dust or in washings taken from hands (Hysong et al., 2003; Pellizzari and Clayton, 2006; Shalat et al., 2006), though air levels of arsenic fume and dust are correlated with urinary arsenic levels at higher occupational inhalational exposures (Jakubowski et al., 1998; Offergelt et al., 1992; Vahter et al., 1986). Though CCA-treated wood contains several thousand times more arsenic than untreated wood, hand washings from children playing on CCA-treated wood compared to children playing on non-CCA-treated wood playground equipment were slightly to fivefold higher (Kwon et al., 2004; Shalat et al., 2006), although urinary arsenic levels were not associated with CCA contact (Shalat et al., 2006).

Levels of total urinary arsenic in the U.S. population in the National Health and Nutrition Examination Survey (NHANES) 2003–2004 were similar to levels reported in the National Human Exposure Assessment Survey (NHEXAS) 1995–1996 for about 80 children residing in the Great Lakes region (Caldwell et al., 2008; Pellizzari and Clayton 2006). In the German Environmental Survey III of 1998, median urinary total arsenic levels in 4052 adults varied with seafood intake, had decreased since the prior 1990–1992 survey, and were about two-fold lower than those for the U.S. population in NHANES 2003–2004 (Schulz et al., 2007; Caldwell et al., 2008). In a Nevada town where groundwater levels were naturally elevated, the median total urinary arsenic in about 200 people was approximately four times higher than that of the U.S. population (Rubin et al., 2007; Caldwell et al., 2008). Compared with this *Report*, higher mean or median total urinary arsenic levels have been reported among people living in specific western areas of North America (Calderon et al., 1999; Josyula et al., 2006; Meza et al., 2004; Valenzuela et al., 2005) and

Urinary Arsenic (V) Acid (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**< LOD**	**< LOD**	**< LOD**	**3.04** (<LOD-3.50)	2568
Age group							
6-11 years	03-04	*	**< LOD**	**< LOD**	**< LOD**	**2.80** (<LOD-4.00)	292
12-19 years	03-04	*	**< LOD**	**< LOD**	**< LOD**	**1.75** (<LOD-2.41)	728
20 years and older	03-04	*	**< LOD**	**< LOD**	**< LOD**	**3.18** (<LOD-3.70)	1548
Gender							
Males	03-04	*	**< LOD**	**< LOD**	**< LOD**	**2.61** (<LOD-3.18)	1284
Females	03-04	*	**< LOD**	**< LOD**	**< LOD**	**3.33** (<LOD-3.89)	1284
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**< LOD**	**< LOD**	**2.69** (<LOD-3.50)	621
Non-Hispanic blacks	03-04	*	**< LOD**	**< LOD**	**< LOD**	**1.75** (<LOD-2.19)	725
Non-Hispanic whites	03-04	*	**< LOD**	**< LOD**	**< LOD**	**3.33** (<LOD-3.95)	1078

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

other areas of the world (Ahsan et al., 2000; Aposhian et al., 2000; Caceres et al., 2005; Sun et al., 2007) with higher levels of arsenic in the drinking water. Median and mean total urinary arsenic levels for residents in some districts in Bangladesh were reported to be about 50-fold higher than respective levels in the U.S. population (Ahsan et al., 2000; Caldwell et al., 2008; Chowdhury et al., 2003). For residents of Inner Mongolia, China, geometric mean levels were about 70-fold higher than for the U.S. population (Sun et al., 2007). Some noncancer effects of arsenic (e.g., dermal keratosis, vasospasm, and peripheral neuropathy) have been associated with urinary levels as low as 50–100 µg/L in chronically exposed populations (ACGIH, 2001; Blom et al., 1985; Tseng et al., 2005; Valenzuela et al., 2005; WHO, 2001). These associations are stronger at higher urinary levels, and other factors such as nutrition, methylation capacity, and duration of exposure are also considered important.

Total arsenic measured in the urine includes all species of inorganic and organic arsenic. Individually measurable species resulting from inorganic arsenic exposure are arsenate, arsenite, and two methylated metabolic products, DMA and MMA. Measurable organic arsenic species in this *Report* are three biologically generated environmental forms, arsenobetaine, arsenocholine, and TMAO. Arsenate, arsenite, arsenocholine, and TMAO were detected in only 7.6, 4.6, 1.8, and 0.3% of a representative sample of the U.S. population in the NHANES 2003–2004 subsample, respectively, with DMA, MMA, and arsenobetaine being the main contributors to the total urinary arsenic levels (Caldwell et al., 2008). When seafood intake is avoided, as evidenced by trace or nondetectable levels of arsenobetaine and arsenocholine in the urine, DMA and MMA compose most (about 75%) of the total arsenic species measured in urine. After recent seafood ingestion, arsenobetaine and arsenocholine will greatly increase the level of total urinary arsenic and comprise the highest percentage of the total urinary arsenic level. The higher percentiles of total urinary arsenic levels in the U.S. population showed a higher contribution of arsenobetaine (Caldwell et al., 2008). In most human studies, DMA has been the predominant metabolite composing the majority of measurable inorganic-related arsenic in the urine (i.e., when seafood organic arsenic is subtracted). Levels of DMA and MMA increase in approximate proportion to the intake of inorganic arsenic. In the late 1980s, a control population of 696 Tacoma residents had median urinary DMA levels similar to those for NHANES 2003–2004 (Kalman et al., 1990; Caldwell et al., 2008). Also, in NHEXAS 1995–1996, Great Lakes region residents had median urinary DMA levels that were slightly less than median levels in NHANES 2003-2004 (Caldwell et al., 2008; Pellizzari and Clayton, 2006). In the residents of a Chilean town who consumed water with high levels of arsenic, median levels of urinary DMA were about 40-fold higher than the adult median reported in NHANES 2003–2004, and urinary DMA represented about 67% of the total urinary arsenic (Hopenhayn-Rich et al., 1996; Caldwell et al., 2008). Detectable levels of MMA reported in NHANES 2003–2004 were found only at the upper percentiles and,

Urinary Arsenobetaine

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**1.55** (1.31-1.83)	**1.00** (.800-1.40)	**5.20** (4.00-6.50)	**16.8** (12.7-22.3)	**35.0** (27.6-44.6)	2568
Age group							
6-11 years	03-04	*	**< LOD**	**1.80** (.800-4.00)	**8.80** (3.90-29.9)	**29.9** (6.20-190)	292
12-19 years	03-04	*	**.600** (.400-.800)	**3.20** (2.00-4.70)	**13.9** (7.20-25.1)	**31.8** (17.2-35.8)	728
20 years and older	03-04	**1.74** (1.48-2.05)	**1.30** (1.00-1.60)	**6.10** (4.90-7.10)	**18.5** (14.0-23.5)	**35.5** (26.8-50.5)	1548
Gender							
Males	03-04	**1.66** (1.43-1.93)	**1.20** (.900-1.50)	**5.80** (4.40-7.10)	**18.6** (13.9-23.7)	**35.0** (26.8-40.5)	1284
Females	03-04	**1.45** (1.17-1.80)	**.900** (.700-1.40)	**4.70** (3.40-6.20)	**15.6** (11.1-25.3)	**32.7** (21.1-51.3)	1284
Race/ethnicity							
Mexican Americans	03-04	**1.19** (.871-1.62)	**.800** (.500-1.30)	**3.20** (1.80-5.20)	**10.2** (6.70-21.4)	**31.4** (16.3-39.1)	621
Non-Hispanic blacks	03-04	**2.29** (1.60-3.28)	**2.00** (1.20-3.50)	**7.70** (5.00-12.0)	**23.7** (13.2-38.7)	**45.6** (25.1-94.0)	725
Non-Hispanic whites	03-04	**1.37** (1.11-1.68)	**.800** (.700-1.20)	**4.30** (2.50-6.30)	**13.3** (9.70-21.4)	**29.3** (21.4-35.5)	1078

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

as with DMA, these levels were much lower than those found in other studies where environmental exposures were highly elevated (Chowdhury et al., 2003; Sun et al., 2007).

In recent years, occupational monitoring and research studies have focused on the sum of inorganic-related species (arsenate + arsenite + DMA + MMA) as a measure of inorganic arsenic intake. Studies of small groups of metal and sulfuric acid smelter workers with varying industrial hygiene conditions have reported urinary inorganic arsenic levels (arsenate + arsenite + DMA + MMA) ranging as high as several hundreds of µg/L during or after work exposure (Jakubowski et al., 1998; Offergelt et al., 1992; Vahter et al., 1986; WHO, 2001). Timber treatment workers had median urinary DMA levels that were about 15-fold higher than the general adult median levels reported in NHANES 2003–2004 (Morton et al., 2006; Caldwell et al., 2008). The American Conference of Governmental Industrial Hygienists (ACGIH) provides an occupational biologic effect index (BEI) for urinary inorganic arsenic plus metabolites equal to 35 µg/L (ACGIH, 2001). The 95th percentile of the U.S. population for the sum of inorganic related species was 18.9 µg/L, which is below the ACGIH BEI (Caldwell et al., 2008). Information about the biological exposure indices is provided here for comparison, not to imply a safety level for general population exposure.

Finding a measurable amount of arsenic in urine does not mean that the level of arsenic causes an adverse health effect. Biomonitoring studies of urinary arsenic can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of arsenic than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Arsenobetaine (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**1.54** (1.30-1.82)	**1.16** (.959-1.43)	**5.00** (3.62-6.91)	**16.2** (12.5-20.3)	**29.4** (24.0-36.4)	2568
Age group							
6-11 years	03-04	*	< LOD	**2.00** (1.15-4.83)	**12.2** (4.13-39.7)	**29.6** (6.80-153)	292
12-19 years	03-04	*	**.531** (.400-.638)	**2.14** (1.39-3.51)	**9.29** (4.29-14.7)	**17.3** (10.4-28.7)	728
20 years and older	03-04	**1.79** (1.51-2.12)	**1.47** (1.15-1.88)	**5.91** (4.32-7.72)	**17.2** (13.4-21.8)	**30.1** (26.1-36.4)	1548
Gender							
Males	03-04	**1.40** (1.18-1.67)	**1.11** (.909-1.28)	**4.78** (3.61-6.70)	**14.4** (11.1-18.5)	**26.5** (18.6-29.9)	1284
Females	03-04	**1.68** (1.37-2.05)	**1.25** (.938-1.67)	**5.58** (3.50-7.43)	**17.2** (12.3-24.5)	**32.9** (25.6-46.3)	1284
Race/ethnicity							
Mexican Americans	03-04	**1.10** (.786-1.55)	**.877** (.612-1.40)	**2.93** (1.78-5.21)	**8.88** (5.50-15.4)	**19.0** (9.64-29.4)	621
Non-Hispanic blacks	03-04	**1.65** (1.19-2.30)	**1.53** (.901-2.45)	**5.81** (4.25-7.82)	**13.6** (9.76-27.9)	**32.9** (13.4-82.1)	725
Non-Hispanic whites	03-04	**1.44** (1.15-1.80)	**1.05** (.833-1.36)	**4.47** (2.73-6.83)	**14.3** (10.9-18.6)	**26.5** (18.6-32.0)	1078

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Arsenocholine

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	< LOD	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	1078

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.6.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Arsenocholine (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	< LOD	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	1078

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Arsenous (III) Acid

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	< LOD	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	**1.40** (<LOD-1.70)	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	**2.00** (<LOD-3.00)	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-1.80)	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	1078

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Arsenous (III) Acid (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	< LOD	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	**1.95** (<LOD-2.76)	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	**3.08** (<LOD-4.44)	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	**2.00** (<LOD-2.29)	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	1078

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Dimethylarsinic Acid

Metabolite of Arsenic

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**3.71** (3.33-4.14)	**3.90** (3.00-4.00)	**6.00** (5.00-7.00)	**11.0** (9.20-12.0)	**16.0** (13.0-17.8)	2568
Age group							
6-11 years	03-04	**3.73** (3.12-4.45)	**4.00** (3.00-4.00)	**6.00** (5.00-7.00)	**9.00** (7.00-12.0)	**12.0** (8.00-22.0)	292
12-19 years	03-04	**3.85** (3.34-4.42)	**4.00** (3.00-4.00)	**6.00** (5.00-7.10)	**9.30** (7.70-12.0)	**13.0** (10.0-16.0)	728
20 years and older	03-04	**3.69** (3.31-4.11)	**3.70** (3.00-4.00)	**6.00** (5.00-7.00)	**11.0** (10.0-12.0)	**16.0** (13.0-19.0)	1548
Gender							
Males	03-04	**4.12** (3.60-4.71)	**4.00** (3.70-4.30)	**6.00** (5.60-7.70)	**11.0** (9.00-15.0)	**17.0** (12.1-22.0)	1284
Females	03-04	**3.37** (3.00-3.78)	**3.00** (3.00-4.00)	**5.50** (4.80-6.20)	**10.0** (8.00-11.0)	**14.0** (11.0-17.7)	1284
Race/ethnicity							
Mexican Americans	03-04	**4.72** (4.27-5.22)	**4.80** (4.00-5.00)	**7.00** (6.00-9.00)	**12.0** (10.0-16.0)	**17.0** (12.0-25.0)	621
Non-Hispanic blacks	03-04	**4.27** (3.71-4.92)	**4.00** (3.50-5.00)	**7.00** (6.00-8.00)	**11.6** (9.00-15.0)	**16.0** (14.0-18.7)	725
Non-Hispanic whites	03-04	**3.27** (2.95-3.62)	**3.00** (3.00-3.80)	**5.00** (4.60-6.00)	**9.00** (7.00-10.0)	**12.0** (9.50-15.0)	1078

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.7.

Urinary Dimethylarsinic Acid (creatinine corrected)

Metabolite of Arsenic

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**3.69** (3.24-4.19)	**3.37** (2.94-3.91)	**5.71** (4.69-6.74)	**9.09** (7.61-11.5)	**13.0** (10.7-16.0)	2568
Age group							
6-11 years	03-04	**4.34** (3.57-5.28)	**4.03** (3.20-4.80)	**6.32** (4.65-8.33)	**10.3** (7.00-13.9)	**13.9** (7.86-21.8)	292
12-19 years	03-04	**2.74** (2.39-3.14)	**2.55** (2.27-2.94)	**3.77** (3.17-4.44)	**5.88** (4.65-6.67)	**7.18** (6.16-11.7)	728
20 years and older	03-04	**3.79** (3.34-4.31)	**3.48** (3.00-4.00)	**5.95** (4.86-7.05)	**9.45** (8.00-12.0)	**13.5** (11.1-18.6)	1548
Gender							
Males	03-04	**3.48** (2.95-4.10)	**3.16** (2.70-3.82)	**5.46** (4.17-6.90)	**8.59** (6.92-12.0)	**12.3** (8.84-18.9)	1284
Females	03-04	**3.89** (3.49-4.34)	**3.57** (3.13-4.06)	**5.78** (4.95-6.67)	**9.32** (8.00-11.5)	**13.7** (10.6-18.6)	1284
Race/ethnicity							
Mexican Americans	03-04	**4.38** (3.80-5.05)	**4.11** (3.29-4.90)	**6.25** (4.84-8.15)	**10.3** (8.00-11.8)	**12.9** (11.1-15.2)	621
Non-Hispanic blacks	03-04	**3.08** (2.69-3.52)	**2.86** (2.60-3.24)	**4.34** (3.82-5.05)	**7.81** (5.82-9.45)	**10.4** (7.61-16.9)	725
Non-Hispanic whites	03-04	**3.44** (2.97-3.98)	**3.17** (2.80-3.73)	**5.16** (4.03-6.49)	**8.00** (6.32-10.9)	**11.1** (8.00-15.4)	1078

Urinary Monomethylarsonic Acid

Metabolite of Arsenic

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	**1.20** (1.00-1.30)	**1.90** (1.60-2.10)	**2.40** (2.00-2.80)	2567
Age group							
6-11 years	03-04	*	< LOD	**1.00** (<LOD-1.40)	**1.80** (1.30-2.60)	**2.30** (1.70-2.90)	292
12-19 years	03-04	*	< LOD	**1.50** (1.10-1.80)	**2.20** (1.70-3.00)	**2.90** (2.20-3.60)	728
20 years and older	03-04	*	< LOD	**1.20** (1.00-1.30)	**1.80** (1.50-2.10)	**2.30** (2.00-2.60)	1547
Gender							
Males	03-04	*	< LOD	**1.30** (1.10-1.60)	**2.00** (1.80-2.40)	**2.60** (2.10-3.00)	1283
Females	03-04	*	< LOD	**1.00** (<LOD-1.20)	**1.60** (1.30-1.90)	**2.10** (1.70-2.60)	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	**1.50** (1.20-1.90)	**2.20** (1.70-2.80)	**2.80** (2.00-4.40)	621
Non-Hispanic blacks	03-04	*	< LOD	**1.10** (<LOD-1.30)	**1.80** (1.40-2.00)	**2.20** (1.70-2.70)	725
Non-Hispanic whites	03-04	*	< LOD	**1.10** (.900-1.30)	**1.80** (1.40-2.00)	**2.10** (1.80-2.50)	1077

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.9.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Monomethylarsonic Acid (creatinine corrected)

Metabolite of Arsenic

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	**1.33** (1.18-1.54)	**2.22** (1.82-2.57)	**2.86** (2.40-3.53)	2567
Age group							
6-11 years	03-04	*	< LOD	**1.63** (<LOD-1.81)	**2.31** (1.88-2.50)	**2.52** (2.31-3.07)	292
12-19 years	03-04	*	< LOD	**1.10** (.853-1.23)	**1.53** (1.30-1.85)	**2.07** (1.71-2.22)	728
20 years and older	03-04	*	< LOD	**1.36** (1.18-1.58)	**2.28** (1.82-2.79)	**3.00** (2.43-3.53)	1547
Gender							
Males	03-04	*	< LOD	**1.20** (1.05-1.36)	**1.88** (1.53-2.34)	**2.50** (2.07-3.45)	1283
Females	03-04	*	< LOD	**1.50** (<LOD-1.77)	**2.40** (1.96-2.86)	**3.00** (2.61-3.53)	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	**1.46** (1.11-1.93)	**2.30** (1.84-3.00)	**3.16** (2.40-3.85)	621
Non-Hispanic blacks	03-04	*	< LOD	**.816** (<LOD-.985)	**1.37** (1.14-1.61)	**1.88** (1.46-2.17)	725
Non-Hispanic whites	03-04	*	< LOD	**1.33** (1.15-1.62)	**2.28** (1.73-2.86)	**2.86** (2.35-3.75)	1077

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Trimethylarsine oxide

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	< LOD	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	1078

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.0.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Trimethylarsine oxide (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2568
Age group							
6-11 years	03-04	*	< LOD	< LOD	< LOD	< LOD	292
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	728
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1548
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	621
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	725
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	1078

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Barium

CAS No. 7440-39-3

General Information

Elemental barium is a silver-white metal which comprises approximately 0.05% of the earth's crust. In nature, it combines with other chemicals such as sulfur or carbon and oxygen. Some barium salts are freely soluble in water, whereas others are practically insoluble (e.g., barium sulfate and barium carbonate). Barium compounds are used by the oil and gas industries to make drilling muds. Barium compounds are also used commercially in paint, bricks, tiles, glass, rubber, depilatories, fireworks, and ceramics. Medically, barium sulfate is used as a contrast medium for taking radiographs of the gastrointestinal tract. Barium salts have also been available as rodenticides.

The general population can be exposed to low amounts of barium in air, water, and food. Certain foods, such as brazil nuts, are high in barium (Genter, 2001). Small amounts of barium can be released into the air during mining and other industrial processes. Workers employed by industries that make or use barium compounds can be exposed to barium dust. In single dose animal studies, soluble forms of barium, such as barium chloride, were relatively well absorbed following inhalation (60-80% of a dose) or ingestion (11-32 % of a dose). Ingested soluble barium

Urinary Barium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.50** (1.35-1.66)	**1.60** (1.50-1.90)	**3.10** (2.70-3.40)	**5.40** (4.60-6.10)	**6.90** (6.20-8.40)	2180
	01-02	**1.52** (1.41-1.65)	**1.63** (1.50-1.76)	**3.12** (2.77-3.51)	**5.24** (4.73-5.84)	**7.48** (6.54-8.12)	2690
	03-04	**1.49** (1.36-1.64)	**1.51** (1.35-1.72)	**2.91** (2.64-3.28)	**5.36** (4.86-5.71)	**7.54** (6.93-8.63)	2558
Age group							
6-11 years	99-00	**2.15** (1.70-2.72)	**2.20** (1.90-2.50)	**4.00** (2.60-6.10)	**6.40** (5.20-8.30)	**8.30** (5.00-76.2)	297
	01-02	**1.80** (1.44-2.26)	**2.09** (1.74-2.49)	**3.63** (2.86-4.39)	**5.37** (4.26-7.38)	**6.88** (5.37-8.49)	368
	03-04	**2.21** (1.81-2.71)	**2.50** (1.81-2.75)	**4.76** (3.80-5.65)	**8.63** (5.59-11.8)	**11.8** (6.87-14.8)	290
12-19 years	99-00	**1.97** (1.78-2.19)	**2.00** (1.70-2.30)	**3.50** (3.10-4.00)	**5.90** (4.80-7.00)	**9.70** (5.90-13.1)	621
	01-02	**2.03** (1.76-2.34)	**2.27** (1.96-2.53)	**4.11** (3.48-4.72)	**6.73** (5.55-7.87)	**9.02** (7.25-11.4)	762
	03-04	**2.16** (1.93-2.41)	**2.35** (2.06-2.63)	**4.11** (3.48-4.71)	**7.18** (6.00-8.29)	**9.63** (8.15-11.4)	725
20 years and older	99-00	**1.36** (1.24-1.51)	**1.50** (1.30-1.70)	**2.80** (2.60-3.20)	**5.10** (4.30-5.50)	**6.40** (5.70-8.40)	1262
	01-02	**1.43** (1.32-1.54)	**1.50** (1.39-1.65)	**2.85** (2.55-3.27)	**4.86** (4.53-5.47)	**7.14** (6.08-8.12)	1560
	03-04	**1.34** (1.20-1.50)	**1.39** (1.19-1.56)	**2.54** (2.21-2.91)	**4.61** (3.99-5.30)	**6.61** (5.57-7.43)	1543
Gender							
Males	99-00	**1.70** (1.54-1.88)	**1.90** (1.80-2.00)	**3.20** (3.00-3.60)	**5.50** (4.20-6.70)	**7.50** (5.90-9.70)	1083
	01-02	**1.64** (1.47-1.82)	**1.80** (1.65-1.98)	**3.15** (2.76-3.73)	**5.52** (4.82-6.35)	**7.87** (6.49-9.32)	1335
	03-04	**1.62** (1.47-1.78)	**1.69** (1.49-1.85)	**3.09** (2.81-3.54)	**5.65** (5.14-6.16)	**8.56** (6.71-9.67)	1281
Females	99-00	**1.33** (1.15-1.53)	**1.50** (1.20-1.60)	**2.80** (2.30-3.30)	**5.20** (4.20-5.90)	**6.80** (5.60-10.4)	1097
	01-02	**1.43** (1.30-1.56)	**1.44** (1.29-1.63)	**3.11** (2.74-3.43)	**4.93** (4.44-5.88)	**7.15** (6.32-7.86)	1355
	03-04	**1.38** (1.24-1.54)	**1.39** (1.18-1.57)	**2.71** (2.41-3.15)	**4.95** (4.29-5.51)	**6.87** (5.65-8.10)	1277
Race/ethnicity							
Mexican Americans	99-00	**1.35** (1.25-1.46)	**1.40** (1.20-1.50)	**2.60** (2.30-2.90)	**4.50** (4.10-5.30)	**6.30** (5.50-6.80)	692
	01-02	**1.21** (1.06-1.37)	**1.25** (1.11-1.46)	**2.56** (2.04-2.91)	**4.35** (3.65-5.49)	**6.43** (5.21-8.22)	683
	03-04	**1.40** (1.15-1.70)	**1.45** (1.22-1.73)	**2.62** (1.78-3.38)	**4.07** (2.95-6.37)	**6.01** (4.01-7.88)	618
Non-Hispanic blacks	99-00	**1.34** (1.12-1.62)	**1.40** (1.20-1.60)	**2.50** (2.30-2.90)	**5.10** (3.70-6.60)	**7.40** (5.40-13.9)	540
	01-02	**1.30** (1.14-1.48)	**1.42** (1.22-1.62)	**2.61** (2.31-2.82)	**4.30** (3.70-5.18)	**5.99** (4.87-7.26)	667
	03-04	**1.27** (1.17-1.39)	**1.38** (1.26-1.48)	**2.34** (2.05-2.59)	**3.77** (3.35-4.36)	**5.86** (4.76-7.45)	723
Non-Hispanic whites	99-00	**1.56** (1.36-1.80)	**1.80** (1.60-2.00)	**3.30** (2.80-3.70)	**5.50** (4.50-6.30)	**7.50** (6.20-8.80)	765
	01-02	**1.61** (1.46-1.77)	**1.68** (1.54-1.85)	**3.31** (2.87-3.74)	**5.66** (4.94-6.30)	**7.73** (6.61-8.49)	1132
	03-04	**1.56** (1.37-1.78)	**1.61** (1.28-1.92)	**3.12** (2.75-3.70)	**5.57** (5.04-6.43)	**8.08** (6.87-9.53)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.12, 0.12, and 0.31, respectively.

was eliminated primarily in feces and to a lesser extent, in urine. Following intravenous injection in animals, about 75 % of a dose of soluble barium was eliminated within 3 days (Reeves, 1986). Insoluble barium salts, such as those used in medical radiographic procedures, are not absorbed when administered.

Human health effects from barium at low environmental doses or at biomonitored levels from low environmental exposures are unknown. The health effects of exposure to barium compounds depend on the dose, chemical form, water solubility, and route of exposure. Toxicity from soluble barium salts is rare, but can occur after intentional or accidental ingestion of barium carbonate in rodenticides (Genter, 2001). Barium blocks cellular efflux of potassium resulting in profound hypokalemia. Symptoms following acute high dose include perioral paresthesias, vomiting, diarrhea, weakness, paralysis, hypertension, and cardiac dysrhythmias. Chronic accumulation of inhaled barium dust in the lung tissue may cause baritosis, a benign condition that may occur among barite ore miners. Chronic exposures to natural low levels of barium in drinking water have not produced general health effects or evidence of cardiovascular risk (Brenniman and Levy, 1984; Wones et al., 1990). Chronic high doses in animals resulted in kidney damage (McCauley et al., 1985; NTP, 1994; Perry et al., 1989). Barium is not rated for human carcinogenicity.

Urinary Barium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.40** (1.26-1.56)	**1.41** (1.28-1.54)	**2.54** (2.20-2.91)	**4.68** (3.85-5.47)	**6.33** (5.47-8.09)	2180
	01-02	**1.44** (1.31-1.58)	**1.49** (1.35-1.63)	**2.76** (2.51-3.03)	**4.58** (4.15-4.96)	**6.24** (5.28-7.27)	2689
	03-04	**1.48** (1.37-1.60)	**1.41** (1.31-1.58)	**2.68** (2.44-2.89)	**4.92** (4.39-5.45)	**7.10** (6.29-7.77)	2558
Age group							
6-11 years	99-00	**2.37** (1.68-3.32)	**2.38** (1.84-2.92)	**4.47** (2.55-6.46)	**10.2** (3.75-22.0)	**11.4** (5.46-22.0)	297
	01-02	**2.20** (1.91-2.52)	**2.41** (2.19-2.83)	**3.91** (3.29-4.51)	**5.01** (4.58-6.00)	**6.71** (5.20-8.47)	368
	03-04	**2.58** (2.22-2.99)	**3.00** (2.35-3.29)	**4.45** (3.57-5.54)	**6.69** (5.59-7.70)	**10.3** (6.53-21.0)	290
12-19 years	99-00	**1.51** (1.34-1.70)	**1.40** (1.26-1.59)	**2.48** (1.97-3.06)	**4.36** (3.23-5.39)	**7.62** (4.24-11.4)	621
	01-02	**1.45** (1.33-1.59)	**1.56** (1.31-1.77)	**2.89** (2.68-3.12)	**4.52** (3.84-5.20)	**5.55** (4.81-6.10)	762
	03-04	**1.54** (1.36-1.75)	**1.59** (1.39-1.87)	**2.60** (2.24-3.48)	**4.97** (4.34-5.58)	**6.47** (5.38-7.77)	725
20 years and older	99-00	**1.30** (1.19-1.42)	**1.33** (1.20-1.46)	**2.32** (2.08-2.62)	**4.29** (3.63-4.96)	**5.65** (5.28-6.33)	1262
	01-02	**1.37** (1.24-1.50)	**1.40** (1.24-1.52)	**2.53** (2.23-2.84)	**4.38** (4.02-5.00)	**6.55** (5.00-7.64)	1559
	03-04	**1.38** (1.26-1.50)	**1.32** (1.22-1.41)	**2.39** (2.13-2.70)	**4.39** (3.77-5.16)	**7.00** (5.45-8.50)	1543
Gender							
Males	99-00	**1.32** (1.22-1.42)	**1.36** (1.23-1.47)	**2.39** (2.11-2.57)	**4.24** (3.48-5.00)	**5.61** (4.39-10.2)	1083
	01-02	**1.30** (1.16-1.45)	**1.34** (1.19-1.50)	**2.46** (2.14-2.83)	**4.51** (3.73-4.96)	**5.42** (4.81-7.51)	1334
	03-04	**1.36** (1.26-1.47)	**1.31** (1.19-1.43)	**2.60** (2.37-2.75)	**4.36** (3.97-4.72)	**6.01** (5.45-6.96)	1281
Females	99-00	**1.49** (1.27-1.74)	**1.48** (1.29-1.68)	**2.65** (2.13-3.46)	**4.91** (3.96-6.38)	**7.36** (5.25-11.3)	1097
	01-02	**1.59** (1.45-1.75)	**1.64** (1.48-1.79)	**2.98** (2.75-3.30)	**4.76** (4.38-5.31)	**6.97** (5.86-7.52)	1355
	03-04	**1.60** (1.45-1.77)	**1.55** (1.35-1.73)	**2.78** (2.34-3.25)	**5.50** (4.43-6.86)	**7.88** (6.28-11.5)	1277
Race/ethnicity							
Mexican Americans	99-00	**1.21** (1.10-1.33)	**1.18** (1.05-1.38)	**2.39** (2.10-2.59)	**4.00** (3.33-4.80)	**5.31** (4.80-6.51)	692
	01-02	**1.18** (1.03-1.34)	**1.16** (1.00-1.38)	**2.33** (1.90-2.61)	**3.68** (3.29-4.10)	**4.96** (4.24-6.80)	682
	03-04	**1.29** (1.08-1.55)	**1.28** (1.03-1.53)	**2.25** (1.73-2.97)	**3.99** (2.79-5.03)	**4.99** (4.24-6.56)	618
Non-Hispanic blacks	99-00	**.881** (.703-1.11)	**.905** (.710-1.06)	**1.64** (1.36-2.00)	**3.27** (2.26-4.76)	**4.84** (3.57-10.8)	540
	01-02	**.891** (.777-1.02)	**.921** (.754-1.11)	**1.64** (1.44-2.03)	**2.86** (2.48-3.37)	**4.02** (3.52-4.68)	667
	03-04	**.915** (.832-1.01)	**.963** (.880-1.04)	**1.51** (1.39-1.75)	**2.62** (2.29-3.04)	**3.76** (3.22-4.72)	723
Non-Hispanic whites	99-00	**1.56** (1.38-1.77)	**1.55** (1.36-1.74)	**2.72** (2.27-3.24)	**5.00** (3.81-6.02)	**6.60** (5.52-10.2)	765
	01-02	**1.62** (1.49-1.76)	**1.66** (1.49-1.82)	**3.04** (2.76-3.32)	**4.96** (4.55-5.41)	**6.74** (5.57-7.64)	1132
	03-04	**1.64** (1.49-1.82)	**1.60** (1.40-1.76)	**2.88** (2.56-3.26)	**5.38** (4.67-6.28)	**7.57** (6.69-9.27)	1074

Workplace standards for external air exposure to various barium salts have been established by OSHA, and a drinking water standard has been established by U.S. EPA. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of urinary barium reflect recent exposure. Studies reporting urinary levels of barium in general populations have found values generally similar to those reported in NHANES 1999-2000, 2001-2002, and 2003-2004 (CDC, 2005; Minoia et al., 1990; Paschal et al., 1998). Barium levels determined in clinically submitted specimens were broadly comparable (Komaromy-Hiller et al., 2000) to levels in NHANES 1999-2000 and 2001-2002. Welders of barium-containing electrodes had median urinary levels of barium that were 60 times higher than the median levels in this *Report*; the welders had no obvious adverse clinical effects (Zschiesche et al., 1992). Urinary concentrations in acute poisonings are often hundreds to thousands of times higher than in this *Report*.

Finding a measurable amount of barium in urine does not mean that the level of barium causes an adverse health effect. Biomonitoring studies of levels of barium provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of barium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Beryllium

CAS No. 7440-41-7

General Information

Pure beryllium is a hard gray metal, the lightest of all metals, and can be found in mineral rocks, coal, soil, and volcanic dust. Beryllium compounds are commercially mined, and refined beryllium is used in mirrors and special metal alloys for the automobile, computer, nuclear, electrical, aircraft, and machine-parts industries. Beryllium is also used in the production of sports equipment such as golf clubs and bike frames. In medicine, beryllium is used in instruments, x-ray machines, and dental bridges. Burning coal and oil can produce small amounts of beryllium dust that can be released into the air.

Exposure to beryllium occurs mostly in the workplace, near some hazardous waste sites, and from breathing tobacco smoke. Two types of minerals, bertrandite and beryl, are mined for commercial recovery of beryllium. Low-level beryllium exposure in the general population can occur through breathing air, eating food, or drinking water containing the metal. In studies of laboratory animals, inhaled insoluble beryllium sulfate was retained in the lungs and nearby lymph nodes; less than one percent of the inhaled dose was slowly absorbed into the blood and eventually incorporated into the skeleton. A half-life of 450

Urinary Beryllium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	2465
	01-02	*	< LOD	< LOD	< LOD	< LOD	2690
	03-04	*	< LOD	< LOD	< LOD	< LOD	2558
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	340
	01-02	*	< LOD	< LOD	< LOD	< LOD	368
	03-04	*	< LOD	< LOD	< LOD	< LOD	290
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	719
	01-02	*	< LOD	< LOD	< LOD	.140 (<LOD-.170)	762
	03-04	*	< LOD	< LOD	< LOD	< LOD	725
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1406
	01-02	*	< LOD	< LOD	< LOD	< LOD	1560
	03-04	*	< LOD	< LOD	< LOD	< LOD	1543
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	1227
	01-02	*	< LOD	< LOD	< LOD	.130 (<LOD-.150)	1335
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1238
	01-02	*	< LOD	< LOD	< LOD	< LOD	1355
	03-04	*	< LOD	< LOD	< LOD	< LOD	1277
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	884
	01-02	*	< LOD	< LOD	< LOD	.130 (<LOD-.160)	683
	03-04	*	< LOD	< LOD	< LOD	< LOD	618
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	568
	01-02	*	< LOD	< LOD	< LOD	< LOD	667
	03-04	*	< LOD	< LOD	< LOD	< LOD	723
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	822
	01-02	*	< LOD	< LOD	< LOD	< LOD	1132
	03-04	*	< LOD	< LOD	< LOD	< LOD	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.13, 0.13, and 0.13, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

days has been calculated for beryllium elimination from the human skeleton (IPCS, 1990).

Human health effects from beryllium at low environmental doses or at biomonitored levels from low environmental exposures are unknown. The effects of occupational exposure to beryllium depend on the concentration of beryllium in the inhaled air and the duration of air exposure. Air levels greater than 100 µg/m3 can result in erythema and edema of the lung mucosa, which produces pneumonitis. Chronic beryllium disease, or berylliosis, is a granulomatous interstitial lung disease that is caused by chronic beryllium inhalation and the resultant immunologic response. Genetic factors modify individual sensitivity to beryllium and susceptibility to developing chronic beryllium disease (McCanlies et al., 2003; Maier, 2002). Skin exposure can result in delayed hypersensitivity reactions, including contact dermatitis and subcutaneous nodules.

Workplace air standards and guidelines for external exposure have been established by OSHA and ACGIH, respectively; and drinking water and environmental standards have been established by U. S. EPA. IARC has classified beryllium as a human carcinogen, based upon excess lung and central nervous system cancers in studies of workers. NTP considers beryllium to be a known human carcinogen. More information about external exposure

Urinary Beryllium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	2465
	01-02	*	< LOD	< LOD	< LOD	< LOD	2689
	03-04	*	< LOD	< LOD	< LOD	< LOD	2558
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	340
	01-02	*	< LOD	< LOD	< LOD	< LOD	368
	03-04	*	< LOD	< LOD	< LOD	< LOD	290
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	719
	01-02	*	< LOD	< LOD	< LOD	**.231** (<LOD-.273)	762
	03-04	*	< LOD	< LOD	< LOD	< LOD	725
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1406
	01-02	*	< LOD	< LOD	< LOD	< LOD	1559
	03-04	*	< LOD	< LOD	< LOD	< LOD	1543
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	1227
	01-02	*	< LOD	< LOD	< LOD	**.281** (<LOD-.333)	1334
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1238
	01-02	*	< LOD	< LOD	< LOD	< LOD	1355
	03-04	*	< LOD	< LOD	< LOD	< LOD	1277
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	884
	01-02	*	< LOD	< LOD	< LOD	**.346** (<LOD-.391)	682
	03-04	*	< LOD	< LOD	< LOD	< LOD	618
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	568
	01-02	*	< LOD	< LOD	< LOD	< LOD	667
	03-04	*	< LOD	< LOD	< LOD	< LOD	723
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	822
	01-02	*	< LOD	< LOD	< LOD	< LOD	1132
	03-04	*	< LOD	< LOD	< LOD	< LOD	1074

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

(i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Urinary beryllium levels represent recent and accumulated exposure. Levels of beryllium in urine for the U.S. population were generally undetectable in NHANES 1999-2000, 2001-2002, and 2003-2004. In other studies, urinary levels for general populations have been either undetectable or had different detection limits than in this *Report* (Komaromy-Hiller et al., 2000; Minoia et al., 1990; Paschal et al., 1998). Hamilton et al. (1994) noted that analytical methods used in several general population studies appeared to have limits of detection that were insufficiently low (i.e., less than 0.1 µg/L). Apostoli and Schaller (2001) stated that detection limits in earlier studies were inadequate to estimate non-occupational exposures. They reported urinary beryllium levels ranging from 0.12 to 0.15 µg/L in workers exposed at the recommended threshold limit value (Apostoli and Schaller, 2001). Given these results, which approximate this *Report's* limit of detection, 0.13 µg/L, and the 95th percentile for males in NHANES 2001-2002, and the fact that most NHANES participant levels were undetectable, it is likely that urinary beryllium levels in the U.S. population are lower than levels in workers.

Finding a measurable amount of beryllium in urine does not mean that the level of beryllium causes an adverse health effect. Biomonitoring studies on levels of beryllium provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of beryllium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Cadmium

CAS No. 7440-43-9

General Information

Cadmium is a soft, malleable, bluish-white metal that is obtained chiefly as a by-product of processing zinc-containing ores (principally sphalerite, as zinc sulfide) and to a lesser extent, during refining of lead and copper from sulfide ore. The predominant commercial use of cadmium is in battery manufacturing. Other uses include pigment production, coatings and plating, plastic stabilizers, and nonferrous alloys. Since 2001, U.S. cadmium use has declined in response to environmental concerns (http://minerals.usgs.gov/minerals/pubs/commodity/cadmium). Important sources of airborne cadmium in the environment are burning fossil fuels such as coal or oil, and incineration of municipal waste materials. Cadmium also may be emitted into the air from zinc, lead, or copper smelters (U.S. EPA,

Blood Cadmium

Geometric mean and selected percentiles of blood concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.412** (.378-.449)	**.400** (.300-.400)	**.600** (.500-.700)	**1.00** (1.00-1.10)	**1.40** (1.30-1.40)	7970
	01-02	*	**.300** (.300-.400)	**.500** (.500-.600)	**1.00** (.900-1.10)	**1.40** (1.20-1.70)	8945
	03-04	**.304** (.289-.320)	**.300** (.300-.300)	**.500** (.500-.600)	**1.10** (1.00-1.20)	**1.60** (1.50-1.60)	8372
Age group							
1-5 years	99-00	*	**< LOD**	**.300** (<LOD-.400)	**.400** (.300-.400)	**.400** (.300-.700)	723
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**.300** (.300-.300)	898
	03-04	*	**< LOD**	**< LOD**	**.200** (.200-.300)	**.200** (.200-.400)	910
6-11 years	99-00	*	**< LOD**	**.300** (<LOD-.400)	**.400** (.300-.500)	**.500** (.400-.500)	905
	01-02	*	**< LOD**	**< LOD**	**.300** (.300-.300)	**.400** (.400-.400)	1044
	03-04	*	**< LOD**	**.200** (<LOD-.200)	**.300** (.200-.300)	**.300** (.300-.300)	856
12-19 years	99-00	**.333** (.304-.366)	**.300** (.300-.400)	**.400** (.400-.500)	**.800** (.600-1.00)	**1.10** (.900-1.20)	2135
	01-02	*	**< LOD**	**.300** (.300-.400)	**.500** (.400-.700)	**.900** (.700-1.20)	2231
	03-04	*	**.200** (<LOD-.200)	**.300** (.300-.300)	**.600** (.500-.700)	**.900** (.800-1.10)	2081
20 years and older	99-00	**.468** (.426-.513)	**.400** (.400-.500)	**.700** (.600-.800)	**1.10** (1.00-1.20)	**1.50** (1.40-1.60)	4207
	01-02	**.425** (.400-.452)	**.400** (.400-.400)	**.600** (.600-.700)	**1.10** (1.00-1.30)	**1.60** (1.40-1.90)	4772
	03-04	**.378** (.359-.398)	**.400** (.300-.400)	**.600** (.600-.700)	**1.20** (1.20-1.30)	**1.80** (1.60-1.90)	4525
Gender							
Males	99-00	**.403** (.368-.441)	**.400** (.300-.400)	**.600** (.500-.700)	**1.00** (.900-1.10)	**1.40** (1.30-1.50)	3913
	01-02	*	**.300** (<LOD-.300)	**.500** (.500-.600)	**1.00** (.900-1.10)	**1.50** (1.20-1.80)	4339
	03-04	**.283** (.266-.300)	**.300** (.200-.300)	**.500** (.500-.500)	**1.10** (1.00-1.20)	**1.60** (1.50-1.60)	4131
Females	99-00	**.421** (.386-.460)	**.400** (.400-.400)	**.600** (.500-.700)	**1.00** (1.00-1.10)	**1.30** (1.20-1.40)	4057
	01-02	**.382** (.362-.403)	**.400** (.300-.400)	**.600** (.500-.600)	**1.00** (.900-1.10)	**1.40** (1.20-1.70)	4606
	03-04	**.326** (.309-.344)	**.300** (.300-.300)	**.600** (.500-.600)	**1.10** (1.00-1.20)	**1.60** (1.50-1.70)	4241
Race/ethnicity							
Mexican Americans	99-00	**.395** (.367-.424)	**.400** (.400-.400)	**.500** (.500-.600)	**.800** (.700-1.00)	**1.20** (.900-1.30)	2742
	01-02	*	**< LOD**	**.400** (.400-.500)	**.600** (.500-.800)	**1.00** (.700-1.30)	2268
	03-04	**.235** (.216-.255)	**.200** (.200-.300)	**.400** (.300-.400)	**.600** (.500-.800)	**1.00** (.800-1.50)	2085
Non-Hispanic blacks	99-00	**.393** (.361-.427)	**.400** (.300-.400)	**.600** (.500-.600)	**1.00** (.900-1.20)	**1.40** (1.20-1.60)	1842
	01-02	*	**.300** (<LOD-.300)	**.500** (.500-.600)	**1.00** (.900-1.10)	**1.40** (1.20-1.70)	2219
	03-04	**.304** (.275-.337)	**.300** (.300-.300)	**.500** (.400-.600)	**1.00** (.900-1.20)	**1.50** (1.30-1.70)	2292
Non-Hispanic whites	99-00	**.420** (.376-.470)	**.400** (.300-.500)	**.600** (.500-.700)	**1.10** (1.00-1.20)	**1.40** (1.30-1.50)	2716
	01-02	*	**.300** (.300-.400)	**.600** (.500-.600)	**1.00** (.900-1.20)	**1.50** (1.30-1.80)	3806
	03-04	**.313** (.296-.331)	**.300** (.300-.300)	**.600** (.500-.600)	**1.10** (1.00-1.20)	**1.60** (1.50-1.70)	3478

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.3, 0.3, and 0.14, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

2000). Cadmium in soil is absorbed by plants, including many food crops such as cereal grains, wheat, rice, potatoes, and various seeds. To a lesser extent, drinking water is a source for cadmium intake.

Cadmium is absorbed via inhalation and ingestion. Inhalation of cigarette smoke is a predominant source of exposure in smokers, whose body burdens of cadmium can be approximately twice that of nonsmokers. For nonsmokers who are not exposed to cadmium in the workplace, ingestion through food is the largest source of exposure. The gastrointestinal absorption of dietary cadmium is about 5% in adult men and 10% or higher in women (Diamond et al., 2003; Horiguchi et al., 2004*a*; Kikuchi et al., 2003), however, individual values vary and are affected by factors such as dietary intake of essential nutrients (iron, calcium, zinc, copper) and protein. Cadmium absorption may be increased with iron deficiency (Berglund et al., 1994), a factor that may contribute to the higher absorption of cadmium by women (Diamond et al., 2003). With chronic exposure, cadmium accumulates in the liver and kidneys where it is bound to metallothionein, an inducible metal binding protein. About one-third to one half of the total body burden accumulates in the kidney tissues (Nordberg and Nordberg, 2001). The estimated half-life of cadmium in the kidney is from one to four decades (ATSDR, 1999; Diamond et al., 2003).

The kidney is a critical target and shows the earliest sign of cadmium toxicity. Renal tubular and glomerular damage,

Urinary Cadmium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.**

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.193** (.169-.220)	**.232** (.214-.249)	**.475** (.436-.519)	**.858** (.763-.980)	**1.20** (1.06-1.34)	2257
	01-02	**.210** (.189-.235)	**.230** (.207-.255)	**.458** (.423-.482)	**.839** (.753-.919)	**1.20** (1.07-1.28)	2690
	03-04	**.211** (.196-.226)	**.210** (.200-.230)	**.450** (.400-.500)	**.800** (.730-.880)	**1.15** (.980-1.26)	2543
Age group							
6-11 years	99-00	*	**.078** (.061-.101)	**.141** (.115-.173)	**.219** (.178-.233)	**.279** (.211-.507)	310
	01-02	**.061** (<LOD-.081)	**.077** (.067-.092)	**.140** (.112-.160)	**.219** (.184-.262)	**.282** (.260-.326)	368
	03-04	**.077** (.065-.090)	**.080** (.060-.090)	**.120** (.100-.160)	**.180** (.160-.310)	**.310** (.170-.610)	287
12-19 years	99-00	**.092** (.067-.126)	**.128** (.107-.148)	**.203** (.183-.232)	**.329** (.272-.372)	**.426** (.366-.596)	648
	01-02	**.109** (.087-.136)	**.135** (.114-.157)	**.210** (.189-.247)	**.327** (.289-.366)	**.452** (.366-.480)	762
	03-04	**.121** (.109-.134)	**.130** (.110-.150)	**.200** (.170-.210)	**.300** (.260-.360)	**.390** (.330-.490)	724
20 years and older	99-00	**.281** (.253-.313)	**.306** (.261-.339)	**.551** (.510-.623)	**.980** (.836-1.13)	**1.32** (1.13-1.57)	1299
	01-02	**.273** (.249-.299)	**.280** (.261-.308)	**.545** (.493-.607)	**.972** (.855-1.06)	**1.28** (1.20-1.43)	1560
	03-04	**.260** (.238-.284)	**.270** (.240-.300)	**.530** (.470-.580)	**.890** (.800-.990)	**1.25** (1.09-1.46)	1532
Gender							
Males	99-00	**.199** (.165-.241)	**.227** (.193-.263)	**.462** (.381-.539)	**.892** (.748-1.15)	**1.41** (.980-1.83)	1121
	01-02	**.201** (.177-.229)	**.223** (.191-.257)	**.445** (.393-.481)	**.875** (.741-1.03)	**1.22** (1.12-1.38)	1335
	03-04	**.206** (.190-.222)	**.210** (.190-.230)	**.440** (.390-.490)	**.790** (.700-.870)	**1.01** (.890-1.25)	1277
Females	99-00	**.187** (.153-.229)	**.239** (.220-.255)	**.492** (.456-.540)	**.818** (.705-.980)	**1.10** (1.01-1.19)	1136
	01-02	**.219** (.192-.251)	**.234** (.202-.265)	**.466** (.433-.519)	**.817** (.733-.886)	**1.17** (.918-1.36)	1355
	03-04	**.216** (.195-.238)	**.210** (.200-.240)	**.450** (.400-.530)	**.820** (.700-.960)	**1.20** (1.02-1.37)	1266
Race/ethnicity							
Mexican Americans	99-00	**.191** (.157-.233)	**.202** (.167-.221)	**.447** (.351-.551)	**.813** (.686-.977)	**1.12** (.886-1.38)	780
	01-02	**.160** (.135-.189)	**.181** (.171-.198)	**.322** (.285-.362)	**.559** (.430-.733)	**.766** (.633-1.15)	683
	03-04	**.175** (.151-.203)	**.170** (.150-.210)	**.350** (.290-.430)	**.680** (.520-.820)	**1.04** (.820-1.20)	614
Non-Hispanic blacks	99-00	**.283** (.208-.387)	**.316** (.243-.412)	**.633** (.498-.806)	**1.22** (.892-1.38)	**1.48** (1.30-1.72)	546
	01-02	**.277** (.229-.336)	**.302** (.257-.354)	**.589** (.476-.713)	**1.04** (.843-1.38)	**1.51** (1.28-1.74)	667
	03-04	**.265** (.237-.295)	**.270** (.220-.320)	**.550** (.440-.640)	**.960** (.810-1.17)	**1.52** (1.06-1.82)	717
Non-Hispanic whites	99-00	**.175** (.148-.206)	**.220** (.194-.246)	**.455** (.388-.510)	**.848** (.714-1.01)	**1.17** (.963-1.47)	760
	01-02	**.204** (.179-.231)	**.221** (.191-.255)	**.445** (.394-.479)	**.817** (.717-.875)	**1.17** (.989-1.24)	1132
	03-04	**.209** (.192-.226)	**.200** (.190-.220)	**.440** (.390-.500)	**.790** (.700-.860)	**1.13** (.940-1.26)	1070

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.06, 0.06, and 0.06, respectively.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.
**All results are corrected for molybdenum oxide interference in the ICP-MS method.

manifested by irreversible proteinuria and progressive reduction in glomerular filtration rate, can result from high dose chronic exposure, most often a result of occupational exposure (Roels et al., 1999). Most studies of relatively low level environmental exposure to cadmium have demonstrated associations between higher urine or blood cadmium levels and an increased prevalence of various biomarkers of renal tubular effects (Alfven et al., 2002; Jarup et al., 2000; Noonan et al., 2002; Olsson et al., 2002; Staessen et al., 1996, 1999). However, two studies in Japan did not find an association between cadmium in urine and renal biomarkers (Ezaki et al., 2003; Horiguchi et al., 2004*b*). Whether the markers of renal tubular effects found in populations with low environmental exposure are likely to progress or predict an increased risk for developing clinically evident renal dysfunction is unknown (Hotz et al., 1999).

During the 1950's and 1960's, a condition known as "itai-itai" ("ouch-ouch") affected postmenopausal women living in a cadmium-polluted region of Japan. This condition of painful osteomalacia or osteoporosis was associated with advanced renal tubular damage that led to increased urinary excretion of calcium and phosphorus and decreased hydroxylation of vitamin D metabolites. Kidney dysfunction that led to osteoporosis was associated with very high urine cadmium levels in residents of an area of China where extensive environmental cadmium pollution occurred (Jin et al., 2004). At lower environmental exposures, older adults and postmenopausal women with

Urinary Cadmium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.**

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.181** (.157-.209)	**.219** (.199-.238)	**.423** (.391-.446)	**.712** (.645-.757)	**.941** (.826-1.07)	2257
	01-02	**.199** (.181-.218)	**.212** (.194-.232)	**.404** (.377-.440)	**.690** (.630-.754)	**.919** (.813-.998)	2689
	03-04	**.210** (.201-.219)	**.208** (.189-.226)	**.412** (.381-.438)	**.678** (.650-.716)	**.940** (.833-1.04)	2543
Age group							
6-11 years	99-00	*	**.085** (.063-.107)	**.148** (.123-.182)	**.210** (.171-.316)	**.316** (.184-.607)	310
	01-02	**.075** (<LOD-.094)	**.100** (.083-.112)	**.166** (.136-.192)	**.233** (.206-.281)	**.318** (.221-.440)	368
	03-04	**.090** (.078-.104)	**.091** (.075-.104)	**.126** (.111-.156)	**.200** (.147-.350)	**.308** (.178-.415)	287
12-19 years	99-00	**.071** (.051-.098)	**.093** (.084-.106)	**.147** (.130-.163)	**.215** (.204-.240)	**.283** (.222-.404)	648
	01-02	**.078** (.067-.091)	**.091** (.085-.101)	**.137** (.123-.143)	**.191** (.175-.234)	**.280** (.234-.321)	762
	03-04	**.086** (.077-.096)	**.084** (.074-.097)	**.122** (.113-.135)	**.176** (.154-.198)	**.234** (.187-.274)	724
20 years and older	99-00	**.267** (.247-.289)	**.288** (.261-.304)	**.484** (.433-.545)	**.769** (.727-.818)	**1.07** (.927-1.17)	1299
	01-02	**.261** (.236-.289)	**.273** (.247-.303)	**.481** (.426-.518)	**.779** (.691-.850)	**.979** (.874-1.12)	1559
	03-04	**.268** (.255-.281)	**.270** (.247-.292)	**.490** (.444-.538)	**.767** (.688-.830)	**1.02** (.909-1.14)	1532
Gender							
Males	99-00	**.154** (.131-.182)	**.176** (.158-.191)	**.329** (.293-.382)	**.617** (.537-.700)	**.789** (.696-.929)	1121
	01-02	**.159** (.143-.177)	**.168** (.157-.182)	**.335** (.304-.364)	**.536** (.491-.653)	**.757** (.690-.856)	1334
	03-04	**.173** (.161-.187)	**.162** (.143-.185)	**.325** (.300-.352)	**.591** (.560-.631)	**.740** (.678-.795)	1277
Females	99-00	**.211** (.170-.261)	**.267** (.239-.308)	**.473** (.423-.551)	**.783** (.690-.917)	**1.09** (.813-1.38)	1136
	01-02	**.245** (.216-.278)	**.263** (.228-.297)	**.479** (.414-.541)	**.792** (.687-.884)	**.985** (.876-1.16)	1355
	03-04	**.252** (.238-.266)	**.253** (.227-.288)	**.487** (.438-.533)	**.802** (.716-.906)	**1.06** (.940-1.21)	1266
Race/ethnicity							
Mexican Americans	99-00	**.175** (.137-.223)	**.181** (.144-.225)	**.331** (.266-.418)	**.622** (.441-.828)	**.856** (.674-1.13)	780
	01-02	**.156** (.136-.178)	**.170** (.150-.184)	**.282** (.263-.340)	**.501** (.388-.614)	**.693** (.507-.839)	682
	03-04	**.163** (.147-.181)	**.159** (.140-.183)	**.296** (.256-.311)	**.531** (.418-.667)	**.718** (.562-.950)	614
Non-Hispanic blacks	99-00	**.183** (.140-.240)	**.202** (.168-.241)	**.414** (.343-.472)	**.663** (.516-.827)	**.873** (.722-.962)	546
	01-02	**.190** (.156-.232)	**.196** (.174-.225)	**.387** (.336-.449)	**.686** (.559-.850)	**.917** (.725-1.08)	667
	03-04	**.190** (.173-.210)	**.185** (.168-.207)	**.338** (.288-.431)	**.700** (.500-.818)	**.865** (.708-1.10)	717
Non-Hispanic whites	99-00	**.175** (.146-.209)	**.219** (.191-.250)	**.432** (.387-.470)	**.729** (.666-.783)	**1.00** (.826-1.16)	760
	01-02	**.205** (.184-.229)	**.224** (.208-.242)	**.421** (.382-.470)	**.719** (.668-.784)	**.931** (.806-1.05)	1132
	03-04	**.220** (.207-.235)	**.221** (.197-.253)	**.434** (.398-.476)	**.687** (.647-.767)	**1.00** (.830-1.08)	1070

* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

**All results are corrected for molybdenum oxide interference in the ICP-MS method.

greater urine cadmium levels may have an increased risk for bone fracture and diminished bone mineral density (Alfven et al., 2002; Staessen et al., 1999).

Acute and heavy exposure to airborne dusts and fumes, as may occur from welding cadmium-alloyed metals, has resulted in severe, potentially fatal pneumonitis (Fernandez et al., 1996). Chronic inhalation exposure to cadmium particulates was associated with changes in pulmonary function and chest radiographs that were consistent with emphysema (Davidson et al., 1988). Workplace exposure to airborne cadmium particulates was associated with decreases in olfactory function (Mascagni et al., 2003). Animal studies have demonstrated reproductive and teratogenic effects. Small epidemiologic studies have noted an inverse relationship between cadmium in cord blood, maternal blood or maternal urine and birth weight (Nishijo et al., 2002; Salpietro et al., 2002) and length at birth (Nishijo et al., 2004; Zhang et al., 2004).

Cadmium can produce lung, pituitary gland and kidney tumors in animals and has been associated with lung cancer in humans in occupational epidemiologic studies. Both IARC and NTP consider cadmium a human carcinogen. Waalkes (2003) provides an overview and summarizes potential mechanisms for carcinogenicity. Workplace standards and guidelines for air exposure to cadmium have been established by OSHA and ACGIH, respectively, and drinking water and environmental standards have been established by U.S. EPA. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Blood cadmium reflects both recent and cumulative exposures. In the typical environmental exposure, urinary cadmium reflects both cumulative exposure and the concentration of cadmium in the kidney.

Surveys of populations not known to have increased cadmium exposure have reported similar urine and blood levels (Becker et al., 2002; Becker et al., 2003; CDC, 2005; Friedman et al., 2006; Komaromy-Hiller et al., 2000; Wennberg et al., 2006; Wilhelm et al., 2006). Women had higher blood and urine cadmium levels compared to men of similar ages, with peak values observed in the fifth to sixth decades (CDC, 2005; Horiguchi et al., 2004*b*; Olsson et al., 2002; Wennberg et al., 2006). For NHANES 1999-2000, blood cadmium was also slightly higher in Mexican Americans and participants 20 years and older (CDC, 2005). Blood and urine cadmium levels are typically higher in cigarette smokers, intermediate in former smokers and lower in never-smokers (Becker et al., 2003; Becker et al., 2002; Mannino et al., 2004; Olsson et al., 2002). Blood cadmium levels are about twice as high in smokers compared to nonsmokers (Becker et al., 2003; Becker et al., 2002; Olsson et al., 2002). Several studies of populations residing in areas with higher cadmium soil concentrations or with frank cadmium pollution have reported mean blood and urine cadmium levels considerably higher (as much as 10 times higher) than control groups or representative U.S. data (CDC, 2005; Ezaki et al., 2003; Jarup et al., 2000; Jin et al., 2004; Staessen et al., 1999; Staessen et al., 1996; Suwazono et al., 2000). Creatinine-corrected urine cadmium values in U.S. study subjects living near a former zinc smelter were similar to those from an unexposed community and to those in this *Report* (Noonan et al., 2002).

People who are occupationally exposed may have blood and urine cadmium levels that are higher than those of the general population. The 95th percentiles for cadmium levels in this *Report* were less than the OSHA standards for both blood cadmium (5 µg/L) and urine cadmium (3 µg/gram of creatinine). Occupational standards are provided here for comparison only, not to imply a safety level for general population exposure.

Subtle increases in markers of renal tubular effects have been associated with urine cadmium levels as low as approximately 1 µg/gram of creatinine (Akesson et al., 2005; Ezaki et al., 2003; Jarup et al., 2000; Moriguchi et al., 2004; Noonan et al., 2002). However, two studies of women in Japan with lower exposures found no correlation between renal tubular effect markers and blood or urine cadmium levels (geometric means were 1.26 and 3.46 µg/gram of creatinine) (Ezaki et al., 2003; Horiguchi et al., 2004*b*). In postmenopausal women, decreased bone density was correlated with mean urinary cadmium levels of approximately 1 µg/gram of creatinine (Staessen et al., 1999). In adults aged 60 years and older, the risk of low bone mineral density increased by nearly three-fold when the blood cadmium exceeded 1.1 µg/L (Alfven et al., 2002). In this *Report* the urinary and blood cadmium levels at the 95th and 90th percentiles, respectively, approached these values associated with subclinical changes in renal function and bone mineral density. Further research is needed to address the public health consequences of such exposure in the United States.

Finding a measurable amount of cadmium in blood or urine does not mean that the levels of cadmium cause an adverse health effect. Biomonitoring studies on levels of cadmium provide physicians and public health officials with reference values so they can determine whether people have been exposed to higher levels of cadmium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Cesium

CAS No. 7440-46-2

General Information

Cesium is a silver-white metal that is found naturally in rock, soil, and clay. Inorganic cesium compounds are used in photomultiplier and vacuum tubes, scintillation counters, infrared lamps, semiconductors, photographic emulsions, and high-power gas-ion devices, and as polymerization catalysts. Radioactive ^{137}Cs has been used medically to treat cancer.

Most human exposure to cesium occurs through the diet. For absorbed cesium salts, the body half-life is estimated to be 70-109 days based on ^{137}Cs exposures. Little is known about the health effects of this metal, although cesium was generally of low toxicity when given to animals. However, cesium hydroxide is corrosive and irritating at high concentrations. Case investigations of ingestions of large doses of cesium chloride have reported decreased appetite, nausea, diarrhea, and cardiac arrhythmia (ATSDR, 2004). Human health effects from cesium at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Workplace guidelines for cesium hydroxide are available from ACGIH and NIOSH. Whether cesium compounds are carcinogenic is unknown.

Urinary Cesium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**4.35** (4.00-4.74)	**4.90** (4.40-5.40)	**7.10** (6.60-7.70)	**9.60** (8.80-10.3)	**11.5** (10.2-13.0)	2464
	01-02	**4.81** (4.40-5.26)	**5.49** (5.12-5.90)	**7.91** (7.47-8.39)	**10.4** (9.56-11.4)	**12.6** (11.1-13.8)	2690
	03-04	**4.67** (4.39-4.97)	**5.14** (4.84-5.49)	**7.68** (7.20-8.21)	**10.6** (9.55-11.4)	**12.7** (11.5-13.9)	2558
Age group							
6-11 years	99-00	**4.87** (4.08-5.81)	**5.70** (4.60-6.70)	**7.30** (6.70-8.00)	**9.00** (7.90-10.1)	**9.70** (9.00-10.8)	340
	01-02	**4.87** (4.08-5.82)	**5.64** (4.69-6.56)	**7.96** (6.77-8.84)	**9.88** (8.64-10.6)	**11.1** (10.2-12.4)	368
	03-04	**5.21** (4.74-5.71)	**5.50** (4.76-6.37)	**8.08** (7.10-8.83)	**11.5** (8.86-12.9)	**12.9** (10.8-13.6)	290
12-19 years	99-00	**4.55** (4.09-5.05)	**5.20** (4.40-5.60)	**6.90** (6.10-7.80)	**8.80** (8.10-9.50)	**10.7** (8.90-12.5)	718
	01-02	**5.22** (4.57-5.95)	**5.62** (5.16-6.12)	**7.55** (7.13-8.04)	**9.77** (9.12-11.1)	**12.0** (10.0-15.0)	762
	03-04	**5.04** (4.59-5.54)	**5.70** (5.16-6.07)	**7.53** (6.91-8.37)	**9.71** (8.80-10.4)	**11.6** (9.92-13.2)	725
20 years and older	99-00	**4.26** (3.94-4.62)	**4.80** (4.40-5.30)	**7.10** (6.50-7.60)	**9.80** (8.90-10.7)	**11.7** (10.2-13.4)	1406
	01-02	**4.74** (4.32-5.20)	**5.43** (5.05-5.87)	**7.97** (7.43-8.52)	**10.6** (9.73-11.5)	**12.9** (11.2-14.2)	1560
	03-04	**4.56** (4.23-4.90)	**5.03** (4.60-5.42)	**7.66** (7.01-8.34)	**10.7** (9.40-11.5)	**12.9** (11.5-14.9)	1543
Gender							
Males	99-00	**4.84** (4.35-5.38)	**5.50** (4.60-6.00)	**7.50** (7.00-8.20)	**9.70** (8.80-11.3)	**11.7** (10.3-13.0)	1226
	01-02	**5.34** (4.89-5.84)	**6.13** (5.61-6.64)	**8.27** (7.84-9.08)	**10.8** (10.1-12.1)	**12.8** (11.3-15.0)	1335
	03-04	**5.03** (4.73-5.36)	**5.59** (5.17-6.00)	**7.98** (7.31-8.63)	**11.0** (9.53-11.8)	**12.9** (11.5-16.1)	1281
Females	99-00	**3.95** (3.63-4.29)	**4.50** (4.20-4.90)	**6.70** (6.20-7.30)	**9.10** (8.30-10.0)	**11.2** (9.90-12.9)	1238
	01-02	**4.36** (3.95-4.81)	**4.87** (4.45-5.25)	**7.33** (6.71-8.01)	**9.77** (9.07-11.0)	**12.4** (10.4-13.8)	1355
	03-04	**4.35** (4.03-4.70)	**4.79** (4.25-5.26)	**7.30** (6.87-7.81)	**10.2** (9.40-11.0)	**12.1** (11.2-13.6)	1277
Race/ethnicity							
Mexican Americans	99-00	**4.32** (3.82-4.89)	**4.80** (4.30-5.20)	**6.70** (6.40-7.20)	**9.10** (8.00-9.90)	**11.1** (9.60-12.7)	884
	01-02	**4.63** (4.10-5.24)	**5.29** (4.59-5.89)	**7.08** (6.42-7.99)	**9.13** (7.86-11.3)	**11.3** (8.81-14.9)	683
	03-04	**4.94** (4.64-5.27)	**5.62** (5.01-6.09)	**7.86** (7.15-8.46)	**10.3** (8.99-11.3)	**11.9** (10.7-14.7)	618
Non-Hispanic blacks	99-00	**4.94** (4.33-5.64)	**5.40** (4.80-6.40)	**7.50** (6.90-8.40)	**9.80** (8.80-10.8)	**11.6** (9.80-13.1)	568
	01-02	**4.93** (4.70-5.17)	**5.33** (5.05-5.64)	**7.36** (6.97-7.59)	**9.44** (8.71-9.68)	**10.7** (10.1-12.3)	667
	03-04	**4.71** (4.47-4.97)	**5.12** (4.71-5.49)	**7.17** (6.72-7.60)	**9.13** (8.52-9.99)	**10.7** (9.99-11.4)	723
Non-Hispanic whites	99-00	**4.25** (3.83-4.72)	**4.80** (4.20-5.50)	**7.20** (6.60-7.90)	**9.70** (8.90-10.7)	**11.8** (10.3-13.3)	821
	01-02	**4.77** (4.27-5.32)	**5.49** (4.99-6.05)	**7.98** (7.45-8.61)	**10.4** (9.54-11.4)	**12.6** (11.0-13.8)	1132
	03-04	**4.56** (4.22-4.94)	**5.02** (4.59-5.42)	**7.60** (7.00-8.23)	**10.7** (9.26-11.8)	**12.9** (11.5-14.7)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.14, 0.14, and 0.2, respectively.

Biomonitoring Information

Urinary cesium levels reflect recent exposure. Two small studies of European populations reported urinary cesium levels similar to U.S. population results shown in this *Report* (Alimonti et al., 2005; Minoia et al., 1990). Using clinically submitted specimens, Komaromy-Hiller et al. (2000) found urinary cesium levels that were slightly lower than those reported for the U.S. population. Urinary cesium levels were similar in a group of forest fire fighters and residents living near the fire area (Wolfe et al., 2004), and were also roughly similar to those in this *Report*.

Finding a measurable amount of cesium in the urine does not mean that the levels of cesium cause an adverse health effect. Biomonitoring studies on levels of cesium can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of cesium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Cesium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**4.10** (3.96-4.25)	**4.13** (3.97-4.27)	**5.41** (5.21-5.70)	**7.14** (6.83-7.50)	**8.64** (8.00-9.30)	2464
	01-02	**4.54** (4.30-4.79)	**4.44** (4.20-4.64)	**6.06** (5.66-6.47)	**8.18** (7.62-8.95)	**10.2** (8.84-11.7)	2689
	03-04	**4.64** (4.42-4.87)	**4.42** (4.21-4.74)	**6.11** (5.76-6.48)	**8.51** (7.99-9.15)	**10.6** (9.75-11.0)	2558
Age group							
6-11 years	99-00	**5.34** (5.03-5.67)	**5.42** (5.03-6.04)	**6.63** (6.18-7.13)	**8.23** (7.13-9.41)	**9.90** (7.88-10.1)	340
	01-02	**5.95** (5.48-6.46)	**5.91** (5.43-6.53)	**7.77** (7.00-8.28)	**9.27** (8.35-11.9)	**11.9** (9.38-12.3)	368
	03-04	**6.07** (5.63-6.53)	**6.02** (5.45-6.49)	**8.30** (7.16-8.99)	**10.8** (9.15-11.8)	**11.9** (10.3-15.8)	290
12-19 years	99-00	**3.43** (3.29-3.58)	**3.54** (3.29-3.68)	**4.35** (4.17-4.56)	**5.31** (4.97-5.79)	**6.67** (5.33-8.09)	718
	01-02	**3.73** (3.41-4.08)	**3.55** (3.36-3.74)	**4.74** (4.40-5.14)	**6.10** (5.35-7.63)	**8.08** (6.44-9.82)	762
	03-04	**3.60** (3.37-3.85)	**3.51** (3.33-3.72)	**4.53** (4.24-4.87)	**6.08** (5.14-6.94)	**7.27** (6.13-9.07)	725
20 years and older	99-00	**4.08** (3.88-4.29)	**4.06** (3.85-4.29)	**5.39** (5.04-5.85)	**7.17** (6.84-7.58)	**8.61** (7.91-9.30)	1406
	01-02	**4.54** (4.30-4.78)	**4.43** (4.20-4.59)	**5.94** (5.64-6.40)	**8.15** (7.46-8.97)	**10.2** (8.74-11.7)	1559
	03-04	**4.68** (4.46-4.91)	**4.47** (4.27-4.80)	**6.11** (5.83-6.43)	**8.47** (7.76-9.17)	**10.5** (9.68-11.2)	1543
Gender							
Males	99-00	**3.78** (3.65-3.91)	**3.78** (3.61-3.96)	**4.96** (4.72-5.20)	**6.50** (6.18-6.70)	**7.71** (7.01-8.64)	1226
	01-02	**4.22** (3.96-4.51)	**4.10** (3.87-4.41)	**5.60** (5.27-6.03)	**7.67** (6.90-8.48)	**9.46** (8.22-11.5)	1334
	03-04	**4.24** (3.99-4.50)	**4.12** (3.89-4.37)	**5.66** (5.19-6.06)	**7.66** (6.90-8.40)	**9.00** (8.36-10.3)	1281
Females	99-00	**4.43** (4.20-4.68)	**4.45** (4.14-4.77)	**5.92** (5.36-6.47)	**7.70** (7.16-8.07)	**9.41** (8.00-10.4)	1238
	01-02	**4.86** (4.58-5.16)	**4.72** (4.50-5.06)	**6.54** (5.93-7.00)	**8.50** (7.84-9.79)	**10.3** (8.95-12.2)	1355
	03-04	**5.05** (4.77-5.35)	**4.77** (4.44-5.14)	**6.58** (6.14-7.22)	**9.43** (8.56-10.5)	**11.3** (10.7-12.3)	1277
Race/ethnicity							
Mexican Americans	99-00	**3.99** (3.73-4.25)	**3.95** (3.65-4.17)	**5.09** (4.79-5.39)	**6.65** (6.08-7.10)	**7.98** (7.20-8.95)	884
	01-02	**4.51** (4.00-5.08)	**4.51** (3.82-4.95)	**5.91** (5.31-6.64)	**7.77** (6.60-10.0)	**10.0** (7.60-20.5)	682
	03-04	**4.58** (4.16-5.05)	**4.51** (4.10-4.92)	**5.74** (5.42-6.09)	**7.53** (6.59-8.91)	**9.44** (8.24-10.6)	618
Non-Hispanic blacks	99-00	**3.21** (2.90-3.56)	**3.26** (3.05-3.44)	**4.30** (4.00-4.55)	**5.50** (5.00-5.98)	**6.33** (5.91-7.04)	568
	01-02	**3.38** (3.19-3.57)	**3.35** (3.05-3.60)	**4.41** (4.15-4.78)	**5.87** (5.63-6.29)	**6.75** (6.41-7.03)	667
	03-04	**3.38** (3.21-3.56)	**3.30** (3.08-3.50)	**4.31** (4.02-4.62)	**5.79** (5.12-6.47)	**6.98** (6.38-7.18)	723
Non-Hispanic whites	99-00	**4.26** (4.07-4.47)	**4.28** (4.05-4.50)	**5.66** (5.26-6.05)	**7.27** (6.84-7.83)	**8.75** (7.93-9.38)	821
	01-02	**4.81** (4.55-5.08)	**4.63** (4.42-4.96)	**6.33** (5.91-6.68)	**8.46** (7.84-9.39)	**10.3** (9.04-11.8)	1132
	03-04	**4.81** (4.52-5.12)	**4.56** (4.31-4.98)	**6.28** (5.95-6.71)	**8.63** (7.99-9.28)	**10.6** (9.43-11.0)	1074

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Cobalt

CAS No. 7440-48-4

General Information

Cobalt is a magnetic element that occurs in nature either as a steel-gray, shiny, hard metal or in combination with other elements. The cobalt used in U.S. industry is imported or obtained by recycling scrap metal that contains cobalt. Among its many uses are manufacturing superalloys used in gas turbines in aircraft engines, hard metal (alloys of cobalt and tungsten carbide), blue-colored pigments, and fertilizers. Cobalt is used as a drying agent in paints, varnishes, and inks. It is also a component of porcelain enamel applied to steel bathroom fixtures, large appliances, and kitchenware. Cobalt compounds are used as catalysts in producing oil and gas, and in synthesizing polyester and other materials. Cobalt compounds are also used in manufacturing battery electrodes, steel-belted radial tires, automobile airbags, diamond-polishing wheels, and magnetic recording media. Medical uses include joint and dental prostheses and radioactive cobalt in cancer chemotherapy.

Cobalt occurs naturally in airborne dust, seawater, and soil. It is emitted into the environment from burning coal and oil and car and truck exhaust. Usual human exposure is from food sources. Cobalt may be released into the systemic circulation of patients who receive joint prostheses that are

Urinary Cobalt

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.375** (.336-.419)	**.410** (.370-.450)	**.630** (.570-.680)	**.950** (.890-1.03)	**1.32** (1.16-1.48)	2465
	01-02	**.379** (.355-.404)	**.410** (.380-.430)	**.610** (.570-.660)	**.940** (.870-1.00)	**1.28** (1.15-1.44)	2690
	03-04	**.316** (.291-.343)	**.330** (.300-.350)	**.520** (.490-.550)	**.820** (.750-.890)	**1.16** (1.08-1.26)	2558
Age group							
6-11 years	99-00	**.499** (.427-.583)	**.530** (.450-.640)	**.750** (.610-.900)	**1.03** (.880-1.12)	**1.22** (1.03-1.50)	340
	01-02	**.452** (.377-.543)	**.520** (.430-.610)	**.710** (.670-.810)	**1.07** (.940-1.21)	**1.32** (1.17-1.53)	368
	03-04	**.454** (.393-.523)	**.460** (.410-.520)	**.750** (.590-.900)	**1.24** (.910-1.47)	**1.68** (1.26-1.81)	290
12-19 years	99-00	**.519** (.463-.581)	**.520** (.490-.570)	**.820** (.670-.890)	**1.17** (1.01-1.47)	**1.52** (1.26-2.56)	719
	01-02	**.515** (.469-.564)	**.520** (.480-.570)	**.750** (.690-.840)	**1.24** (1.07-1.32)	**1.59** (1.37-1.99)	762
	03-04	**.461** (.428-.496)	**.480** (.450-.520)	**.740** (.650-.800)	**1.03** (.940-1.23)	**1.60** (1.14-1.92)	725
20 years and older	99-00	**.343** (.305-.386)	**.370** (.330-.420)	**.570** (.520-.640)	**.880** (.810-.980)	**1.28** (1.07-1.39)	1406
	01-02	**.352** (.333-.373)	**.380** (.350-.410)	**.560** (.520-.590)	**.860** (.800-.930)	**1.15** (1.04-1.42)	1560
	03-04	**.285** (.259-.313)	**.300** (.270-.330)	**.460** (.410-.510)	**.690** (.660-.730)	**1.06** (.890-1.14)	1543
Gender							
Males	99-00	**.371** (.331-.416)	**.410** (.370-.450)	**.580** (.540-.640)	**.820** (.740-.900)	**1.01** (.900-1.12)	1227
	01-02	**.367** (.338-.399)	**.390** (.360-.420)	**.550** (.520-.600)	**.790** (.740-.850)	**1.05** (.960-1.14)	1335
	03-04	**.294** (.270-.319)	**.320** (.290-.340)	**.480** (.440-.500)	**.670** (.620-.710)	**.870** (.790-.920)	1281
Females	99-00	**.379** (.333-.431)	**.410** (.340-.460)	**.680** (.590-.790)	**1.17** (.930-1.36)	**1.50** (1.28-2.05)	1238
	01-02	**.390** (.364-.417)	**.430** (.400-.450)	**.670** (.620-.700)	**1.06** (.980-1.16)	**1.46** (1.22-1.81)	1355
	03-04	**.339** (.308-.372)	**.340** (.310-.370)	**.580** (.540-.610)	**1.04** (.900-1.13)	**1.47** (1.33-1.73)	1277
Race/ethnicity							
Mexican Americans	99-00	**.418** (.348-.502)	**.470** (.370-.530)	**.670** (.630-.770)	**1.05** (.950-1.19)	**1.47** (1.25-1.67)	884
	01-02	**.398** (.373-.424)	**.430** (.410-.450)	**.650** (.600-.710)	**.950** (.850-1.03)	**1.20** (1.06-1.48)	683
	03-04	**.374** (.350-.398)	**.350** (.340-.390)	**.580** (.530-.620)	**1.09** (.920-1.16)	**1.33** (1.16-1.73)	618
Non-Hispanic blacks	99-00	**.434** (.405-.465)	**.430** (.390-.470)	**.680** (.620-.760)	**1.17** (1.04-1.26)	**1.45** (1.23-2.04)	568
	01-02	**.435** (.388-.487)	**.420** (.380-.460)	**.650** (.540-.810)	**1.16** (.850-1.64)	**1.75** (1.32-2.22)	667
	03-04	**.380** (.348-.414)	**.380** (.360-.410)	**.600** (.540-.680)	**1.01** (.890-1.09)	**1.28** (1.01-2.03)	723
Non-Hispanic whites	99-00	**.369** (.316-.431)	**.410** (.350-.460)	**.630** (.550-.700)	**.930** (.830-1.08)	**1.29** (1.02-1.65)	822
	01-02	**.359** (.327-.394)	**.390** (.360-.430)	**.590** (.520-.660)	**.870** (.800-.950)	**1.16** (1.04-1.32)	1132
	03-04	**.301** (.270-.334)	**.310** (.280-.340)	**.500** (.460-.540)	**.760** (.690-.850)	**1.09** (.950-1.26)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.07, 0.07, and 0.08, respectively.

fabricated from cobalt alloys (Lhotka et al., 2003). Cobalt constitutes 4% by weight of vitamin B-12 (cobalamin), an essential human nutrient. A nutritional requirement for cobalt other than that contained within dietary cobalamin has not been established. Exposure in the workplace may come from electroplating, refining or processing alloys, using hard metal cutting tools, or using diamond-polishing wheels that contain cobalt metal. Workplace standards and guidelines for external air exposure to cobalt and several of its compounds have been established by OSHA and ACGIH, respectively.

Cobalt is absorbed by oral and pulmonary routes. Human studies with ^{60}Co administered as soluble cobalt chloride have reported oral absorption ranging from approximately 1 to 25 % (Smith et al., 1972). Once absorbed and distributed in the body, cobalt is excreted predominantly in the urine, and to a lesser extent, in the feces. Elimination reflects a multi-compartmental model dominated by compartments with half-lives on the order of several hours to a week, but with a minor fraction (10-15 %) exhibiting a half-life of several years (Mosconi et al., 1994; Smith et al., 1972). A portion of cobalt retained for long periods is concentrated in the liver. Lung retention of relatively insoluble cobalt compounds such as cobalt oxide may be prolonged, with pulmonary clearance half-lives of from one to two years (Hedge et al., 1979). Recent inhalation exposure to soluble cobalt compounds can be monitored by measuring cobalt in urine or blood (Lison et al., 1994).

Urinary Cobalt (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.353** (.319-.391)	**.328** (.302-.365)	**.515** (.457-.581)	**.821** (.679-.963)	**1.16** (.938-1.50)	2465
	01-02	**.358** (.333-.384)	**.335** (.313-.360)	**.523** (.487-.562)	**.844** (.750-.955)	**1.16** (1.00-1.28)	2689
	03-04	**.314** (.303-.325)	**.290** (.278-.306)	**.455** (.434-.481)	**.737** (.703-.781)	**1.02** (.911-1.10)	2558
Age group							
6-11 years	99-00	**.547** (.467-.640)	**.554** (.449-.647)	**.774** (.626-.938)	**1.00** (.833-1.49)	**1.25** (.895-1.50)	340
	01-02	**.552** (.508-.599)	**.548** (.503-.609)	**.756** (.660-.829)	**1.00** (.900-1.27)	**1.30** (1.03-1.73)	368
	03-04	**.529** (.471-.593)	**.500** (.463-.543)	**.689** (.634-.750)	**1.04** (.760-1.29)	**1.29** (1.04-1.36)	290
12-19 years	99-00	**.391** (.353-.433)	**.378** (.329-.407)	**.537** (.469-.595)	**.824** (.638-1.17)	**1.44** (.821-3.54)	719
	01-02	**.368** (.343-.396)	**.352** (.327-.372)	**.534** (.471-.611)	**.851** (.673-.949)	**1.06** (.932-1.24)	762
	03-04	**.329** (.304-.355)	**.316** (.277-.348)	**.495** (.442-.561)	**.738** (.630-.847)	**.952** (.792-1.09)	725
20 years and older	99-00	**.328** (.297-.362)	**.306** (.280-.328)	**.471** (.428-.522)	**.727** (.632-.905)	**1.12** (.861-1.36)	1406
	01-02	**.337** (.313-.363)	**.313** (.294-.337)	**.475** (.435-.513)	**.792** (.704-.955)	**1.15** (.963-1.33)	1559
	03-04	**.293** (.282-.304)	**.271** (.257-.286)	**.400** (.380-.429)	**.691** (.616-.744)	**.976** (.829-1.10)	1543
Gender							
Males	99-00	**.290** (.259-.324)	**.279** (.248-.301)	**.402** (.365-.449)	**.608** (.534-.728)	**.838** (.667-1.10)	1227
	01-02	**.290** (.272-.310)	**.278** (.256-.297)	**.392** (.361-.425)	**.644** (.574-.707)	**.848** (.786-.929)	1334
	03-04	**.247** (.237-.259)	**.234** (.215-.250)	**.333** (.313-.352)	**.513** (.476-.585)	**.700** (.630-.753)	1281
Females	99-00	**.426** (.378-.479)	**.407** (.362-.457)	**.606** (.550-.694)	**.960** (.781-1.29)	**1.50** (1.11-1.83)	1238
	01-02	**.435** (.404-.468)	**.408** (.382-.438)	**.635** (.560-.708)	**1.00** (.879-1.19)	**1.29** (1.12-1.60)	1355
	03-04	**.393** (.378-.409)	**.361** (.342-.381)	**.554** (.513-.615)	**.937** (.850-1.00)	**1.29** (1.10-1.33)	1277
Race/ethnicity							
Mexican Americans	99-00	**.386** (.339-.439)	**.376** (.333-.419)	**.598** (.500-.669)	**.898** (.826-1.00)	**1.23** (1.11-1.35)	884
	01-02	**.388** (.361-.417)	**.361** (.333-.394)	**.591** (.500-.662)	**.872** (.777-.990)	**1.10** (.990-1.27)	682
	03-04	**.346** (.326-.368)	**.327** (.296-.349)	**.542** (.487-.594)	**.850** (.753-.963)	**1.14** (.963-1.35)	618
Non-Hispanic blacks	99-00	**.282** (.275-.289)	**.257** (.243-.279)	**.417** (.378-.462)	**.723** (.600-.785)	**.975** (.757-1.60)	568
	01-02	**.298** (.275-.323)	**.268** (.251-.296)	**.444** (.393-.505)	**.728** (.582-.917)	**1.03** (.740-1.55)	667
	03-04	**.273** (.248-.300)	**.259** (.239-.281)	**.388** (.344-.461)	**.700** (.563-.842)	**.964** (.733-1.15)	723
Non-Hispanic whites	99-00	**.369** (.324-.421)	**.352** (.313-.387)	**.533** (.452-.611)	**.861** (.667-1.16)	**1.25** (.895-1.57)	822
	01-02	**.362** (.331-.396)	**.343** (.313-.368)	**.523** (.479-.562)	**.830** (.736-.983)	**1.16** (.983-1.33)	1132
	03-04	**.317** (.301-.334)	**.291** (.274-.309)	**.457** (.425-.488)	**.738** (.683-.804)	**1.00** (.857-1.13)	1074

Toxic effects of cobalt have been encountered in workplace settings. Cobalt compounds are a recognized cause of allergic contact dermatitis (Dickel et al., 2001; Lisi, 2003; Thomassen et al., 2001). Occupational exposure to cobalt-containing dusts has caused occupational asthma (Pisati and Zedda, 1994; Shirakawa et al., 1989). "Hard metal" disease, an interstitial lung disorder with findings that range from alveolitis to pulmonary fibrosis, has been associated with exposure to dusts that contain cobalt, usually in combination with tungsten carbide (Cugell et al., 1990). The extent to which cobalt exposure alone causes interstitial lung disease is unknown (Linna et al., 2003; Swennen et al., 1993).

Cobalt was once added as a foaming agent to beer, and this caused outbreaks of cardiomyopathy among heavy drinkers in the mid-1960's (Alexander et al., 1972). Case reports have also suggested a link between occupational cobalt exposure and cardiomyopathy (Jarvis et al., 1992). Cobalt compounds appear to stimulate erythropoietin production and were formerly used in the treatment of anemia (Goldberg et al., 1988). Pharmaceutical preparations of cobalt used in the past as hematinics were associated with the development of overt hypothyroidism (Kriss et al., 1955). A subclinical decrease in thyroid production was observed in a study of cobalt production workers (Swennen et al., 1993).

Cobalt compounds elicited numerous genotoxic effects in both *in vitro* and *in vivo* assays (De Boeck et al., 2003) and produced lung cancer in rats and mice after chronic inhalation (Bucher et al., 1999). An industry-wide study of hard metal workers in France observed an increased mortality from lung cancer (Moulin et al., 1998). IARC has classified cobalt metal with tungsten carbide and other soluble cobalt salts as possibly carcinogenic to humans. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Urinary levels of cobalt decline rapidly within 24 hours after exposure ceases (Alexandersson et al., 1988). Urinary measurements mainly reflect recent exposure, although substantial occupational exposures have produced elevated urinary levels for many weeks. Smaller population surveys of European adults reported urinary cobalt levels that were roughly similar U.S. population results in this *Report* (Kristiansen et al., 1997; White and Sabbioni, 1998). Small studies of patients with hip replacements using metal alloy prostheses reported increased urinary cobalt concentrations, with mean levels that were about 15-20 times higher than in the general U.S. population (CDC, 2005; Daniel et al., 2006; Dunstan et al., 2005; Iavicoli et al., 2006; MacDonald et al., 2003).

Persons with occupational exposure to cobalt often have urinary cobalt levels that are many times higher than those of the general population. The ACGIH biological exposure index (BEI) for inorganic forms of cobalt (except insoluble cobalt oxides) is 15 µg/L. Information about the BEI is provided here for comparison, not to imply that the BEI is a safe level for general population exposure. For workers exposed to cobalt in the air, a distinction is made between soluble and insoluble (oxides and metallic) cobalt (Christensen and Poulsen, 1994; Lison et al., 1994). Exposure to soluble cobalt salts will produce proportionately higher urinary levels because they are absorbed better. Correlations between air exposure levels and urinary cobalt levels in hard metal fabricators are well documented (Ichikawa et al., 1985; Krause et al., 2001; Lauwerys and Hoet, 2001; Linnainmaa and Kiilunen, 1997).

Finding a measurable amount of cobalt in the urine does not mean that the levels of cobalt cause an adverse health effect. Biomonitoring studies on levels of cobalt provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of cobalt than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Lead

CAS No. 7439-92-1

General Information

Elemental lead is a soft, malleable, dense, blue-gray metal that occurs naturally in soils and rocks. Lead is most often mined from ores or recycled from scrap metal or batteries. Elemental lead can be combined with other elements to form inorganic and organic compounds, such as lead phosphate and tetraethyl lead. Lead has a variety of uses in manufacturing: storage batteries, solders, metal alloys (e.g. brass, bronze), plastics, leaded glass, ceramic glazes, ammunition, antique-molded or cast ornaments, and for radiation shielding. In the past, lead was added to gasoline and residential paints and used in soldering the seams of food cans. Lead was used in plumbing for centuries and may still be present.

Before the 1980's, the main source of lead exposure for the general U.S. population was aerosolized lead emitted from combustion engines that used leaded gasoline. Aerosolized lead is either inhaled or ingested after it is deposited on surfaces and food crops. Since lead has been eliminated from gasoline, adult lead exposures tend to be limited to

Blood Lead

Geometric mean and selected percentiles of blood concentrations (in µg/dL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**1.66** (1.60-1.72)	**1.60** (1.60-1.70)	**2.50** (2.40-2.60)	**3.80** (3.60-4.00)	**5.00** (4.70-5.50)	7970
	01-02	**1.45** (1.39-1.51)	**1.40** (1.40-1.50)	**2.20** (2.10-2.30)	**3.40** (3.20-3.60)	**4.50** (4.20-4.70)	8945
	03-04	**1.43** (1.36-1.50)	**1.40** (1.30-1.50)	**2.10** (2.10-2.20)	**3.20** (3.10-3.30)	**4.20** (3.90-4.40)	8373
Age group							
1-5 years	99-00	**2.23** (1.96-2.53)	**2.20** (1.90-2.50)	**3.40** (2.80-3.90)	**4.90** (4.00-6.60)	**7.00** (6.10-8.30)	723
	01-02	**1.70** (1.55-1.87)	**1.60** (1.50-1.80)	**2.50** (2.20-2.90)	**4.20** (3.50-5.20)	**5.80** (4.70-6.90)	898
	03-04	**1.77** (1.60-1.95)	**1.70** (1.50-1.90)	**2.50** (2.30-2.80)	**3.90** (3.30-4.60)	**5.10** (4.10-6.60)	911
6-11 years	99-00	**1.51** (1.36-1.66)	**1.40** (1.30-1.60)	**2.10** (1.80-2.50)	**3.30** (2.80-3.80)	**4.50** (3.40-6.20)	905
	01-02	**1.25** (1.14-1.36)	**1.20** (1.00-1.30)	**1.70** (1.60-2.00)	**2.80** (2.50-3.10)	**3.70** (3.00-4.70)	1044
	03-04	**1.25** (1.12-1.39)	**1.20** (1.10-1.40)	**1.80** (1.50-2.10)	**2.60** (2.10-3.10)	**3.30** (2.50-4.60)	856
12-19 years	99-00	**1.10** (1.04-1.17)	**1.10** (1.00-1.20)	**1.50** (1.40-1.70)	**2.30** (2.10-2.40)	**2.90** (2.70-3.00)	2135
	01-02	**.942** (.899-.986)	**.900** (.900-1.00)	**1.30** (1.20-1.40)	**2.00** (1.90-2.10)	**2.70** (2.40-2.90)	2231
	03-04	**.946** (.878-1.02)	**.900** (.800-1.00)	**1.30** (1.20-1.40)	**1.90** (1.70-2.10)	**2.60** (2.20-3.00)	2081
20 years and older	99-00	**1.75** (1.68-1.81)	**1.70** (1.60-1.80)	**2.60** (2.50-2.70)	**3.90** (3.70-4.10)	**5.20** (4.80-5.60)	4207
	01-02	**1.56** (1.49-1.62)	**1.60** (1.50-1.60)	**2.30** (2.30-2.40)	**3.60** (3.40-3.70)	**4.60** (4.30-5.00)	4772
	03-04	**1.52** (1.45-1.60)	**1.50** (1.40-1.60)	**2.30** (2.20-2.40)	**3.30** (3.20-3.50)	**4.30** (4.00-4.60)	4525
Gender							
Males	99-00	**2.01** (1.93-2.09)	**1.90** (1.90-2.00)	**2.90** (2.80-3.00)	**4.50** (4.10-4.80)	**6.00** (5.50-6.50)	3913
	01-02	**1.78** (1.71-1.86)	**1.80** (1.70-1.80)	**2.70** (2.50-2.80)	**3.90** (3.80-4.10)	**5.40** (5.00-5.50)	4339
	03-04	**1.69** (1.62-1.75)	**1.60** (1.50-1.70)	**2.50** (2.40-2.60)	**3.70** (3.40-3.90)	**4.80** (4.50-5.20)	4132
Females	99-00	**1.37** (1.32-1.43)	**1.30** (1.30-1.40)	**2.00** (1.90-2.10)	**3.10** (2.90-3.30)	**4.00** (3.80-4.20)	4057
	01-02	**1.19** (1.14-1.25)	**1.20** (1.10-1.20)	**1.80** (1.70-1.90)	**2.60** (2.50-2.80)	**3.60** (3.10-4.00)	4606
	03-04	**1.22** (1.14-1.31)	**1.20** (1.10-1.30)	**1.80** (1.70-2.00)	**2.70** (2.50-3.00)	**3.50** (3.10-3.80)	4241
Race/ethnicity							
Mexican Americans	99-00	**1.83** (1.75-1.91)	**1.80** (1.70-1.90)	**2.80** (2.60-2.90)	**4.20** (3.90-4.60)	**5.80** (5.10-6.60)	2742
	01-02	**1.46** (1.34-1.60)	**1.50** (1.30-1.60)	**2.30** (2.10-2.60)	**3.60** (3.40-4.20)	**5.40** (4.40-6.70)	2268
	03-04	**1.55** (1.43-1.69)	**1.50** (1.40-1.60)	**2.30** (2.10-2.50)	**3.50** (2.90-4.20)	**4.90** (3.90-6.40)	2085
Non-Hispanic blacks	99-00	**1.87** (1.75-2.00)	**1.80** (1.70-2.00)	**2.80** (2.60-3.00)	**4.30** (4.00-4.60)	**5.70** (5.20-6.10)	1842
	01-02	**1.65** (1.52-1.80)	**1.60** (1.40-1.70)	**2.60** (2.30-2.90)	**4.20** (3.80-4.70)	**5.80** (5.30-6.50)	2219
	03-04	**1.69** (1.52-1.89)	**1.60** (1.40-1.80)	**2.60** (2.20-3.00)	**4.10** (3.50-4.70)	**5.30** (4.60-6.60)	2293
Non-Hispanic whites	99-00	**1.62** (1.55-1.69)	**1.60** (1.50-1.70)	**2.40** (2.30-2.50)	**3.60** (3.40-3.90)	**5.00** (4.40-5.70)	2716
	01-02	**1.43** (1.37-1.48)	**1.40** (1.30-1.50)	**2.20** (2.10-2.20)	**3.20** (3.10-3.40)	**4.20** (3.90-4.50)	3806
	03-04	**1.37** (1.32-1.43)	**1.30** (1.30-1.40)	**2.10** (2.00-2.10)	**3.00** (2.80-3.20)	**3.90** (3.60-4.30)	3478

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.3, 0.3, and 0.28, respectively.

occupational (e.g., battery and radiator manufacturing) and recreational sources. However, the primary source of exposure in children is from deteriorated lead-based paint and the resulting dust and soil contamination (Manton et al., 2000). Children may also be exposed to lead brought into the home on the work clothes of adults whose work involves lead. Less common sources of incidental or unique lead exposure are numerous: lead-glazed ceramic pottery; stained glass framing; pewter utensils and drinking vessels; older plumbing systems with leaded pipes or lead soldered connections; lead-based painted surfaces undergoing renovation or demolition; imported children's trinkets and toys; lead-containing folk remedies and cosmetics; bullet fragments retained in human tissue; lead-contaminated dust in indoor firing ranges; and contact with soil, dust, or water contaminated by mining or smelting operations. Small amounts of environmental lead also may result from burning fossil fuels (ATSDR, 2007; CDC, 1991).

Lead is absorbed into the body after fine lead particulates or fumes are inhaled, or after soluble lead compounds are ingested. Absorption of ingested lead can be as much as five times greater in children than adults and even greater when intakes of dietary minerals are deficient. In the blood, absorbed lead is bound to erythrocytes and then is distributed initially to multiple soft tissues and eventually into bone. Approximately half of the absorbed lead may be incorporated into bone, which is the site of approximately

Urinary Lead

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.766** (.708-.828)	**.800** (.800-.900)	**1.40** (1.30-1.50)	**2.20** (2.00-2.30)	**2.90** (2.60-3.30)	2465
	01-02	**.677** (.637-.718)	**.700** (.700-.800)	**1.20** (1.20-1.30)	**2.00** (1.90-2.20)	**2.70** (2.50-2.80)	2690
	03-04	**.636** (.595-.680)	**.640** (.580-.690)	**1.04** (.960-1.12)	**1.73** (1.52-1.86)	**2.29** (2.03-2.62)	2558
Age group							
6-11 years	99-00	**1.07** (.955-1.20)	**1.10** (.900-1.30)	**1.50** (1.40-1.70)	**2.40** (1.80-3.10)	**3.40** (2.40-5.00)	340
	01-02	**.753** (.661-.857)	**.800** (.600-.900)	**1.20** (1.10-1.40)	**2.10** (1.60-2.40)	**2.60** (2.10-3.70)	368
	03-04	**.795** (.671-.941)	**.790** (.640-.900)	**1.35** (.970-1.86)	**2.27** (1.62-4.09)	**3.33** (2.23-4.41)	290
12-19 years	99-00	**.659** (.579-.749)	**.700** (.600-.800)	**1.10** (.900-1.30)	**1.80** (1.40-2.20)	**2.20** (1.90-2.80)	719
	01-02	**.564** (.526-.605)	**.600** (.500-.600)	**1.00** (.800-1.10)	**1.60** (1.40-1.70)	**2.00** (1.80-2.40)	762
	03-04	**.604** (.553-.660)	**.630** (.570-.680)	**.920** (.810-1.02)	**1.32** (1.14-1.80)	**1.86** (1.44-2.29)	725
20 years and older	99-00	**.752** (.691-.818)	**.800** (.700-.900)	**1.40** (1.30-1.50)	**2.20** (2.00-2.40)	**2.90** (2.60-3.30)	1406
	01-02	**.688** (.641-.738)	**.700** (.700-.800)	**1.20** (1.20-1.30)	**2.00** (1.90-2.30)	**2.80** (2.50-2.90)	1560
	03-04	**.625** (.579-.674)	**.620** (.560-.700)	**1.04** (.960-1.11)	**1.70** (1.52-1.80)	**2.21** (2.04-2.49)	1543
Gender							
Males	99-00	**.923** (.822-1.04)	**.900** (.900-1.00)	**1.60** (1.40-1.80)	**2.50** (2.20-2.90)	**3.40** (2.90-3.80)	1227
	01-02	**.808** (.757-.862)	**.800** (.800-.900)	**1.40** (1.30-1.50)	**2.50** (2.20-2.70)	**3.20** (2.90-3.50)	1335
	03-04	**.731** (.680-.785)	**.730** (.680-.800)	**1.17** (1.07-1.27)	**2.03** (1.78-2.22)	**2.66** (2.33-2.91)	1281
Females	99-00	**.642** (.589-.701)	**.700** (.600-.800)	**1.20** (1.10-1.30)	**1.90** (1.60-2.20)	**2.40** (2.10-3.00)	1238
	01-02	**.573** (.535-.613)	**.600** (.600-.600)	**1.10** (1.00-1.10)	**1.60** (1.50-1.80)	**2.20** (1.90-2.40)	1355
	03-04	**.558** (.506-.616)	**.540** (.480-.620)	**.920** (.820-1.04)	**1.49** (1.24-1.75)	**1.82** (1.59-2.30)	1277
Race/ethnicity							
Mexican Americans	99-00	**1.02** (.915-1.13)	**1.10** (.900-1.20)	**1.80** (1.60-1.90)	**2.90** (2.50-3.40)	**4.30** (3.10-5.40)	884
	01-02	**.833** (.745-.931)	**.900** (.700-1.00)	**1.50** (1.20-1.70)	**2.50** (2.00-2.90)	**3.30** (2.70-3.80)	683
	03-04	**.815** (.710-.935)	**.840** (.700-.990)	**1.31** (1.18-1.59)	**2.19** (1.86-2.50)	**2.66** (2.13-3.97)	618
Non-Hispanic blacks	99-00	**1.11** (1.00-1.23)	**1.10** (1.00-1.20)	**1.90** (1.50-2.10)	**3.00** (2.40-3.50)	**4.20** (3.30-5.70)	568
	01-02	**.940** (.833-1.06)	**.900** (.800-1.00)	**1.60** (1.30-1.80)	**2.70** (2.10-3.40)	**3.70** (2.90-4.80)	667
	03-04	**.848** (.729-.986)	**.850** (.710-1.00)	**1.40** (1.10-1.72)	**2.14** (1.78-2.64)	**2.82** (2.31-3.89)	723
Non-Hispanic whites	99-00	**.695** (.625-.773)	**.700** (.700-.900)	**1.30** (1.10-1.40)	**2.00** (1.80-2.40)	**2.70** (2.30-3.10)	822
	01-02	**.610** (.572-.651)	**.700** (.600-.700)	**1.10** (1.10-1.20)	**1.90** (1.70-2.00)	**2.40** (2.30-2.60)	1132
	03-04	**.591** (.556-.628)	**.590** (.540-.650)	**.960** (.910-.990)	**1.52** (1.40-1.75)	**2.14** (1.78-2.51)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.1, 0.1, and 0.33, respectively.

90% of the body lead burden in most adults. The skeleton acts as a storage depot, and approximately 40 to 70% of lead in blood comes from the skeleton in environmentally exposed adults (Smith et al., 1996). Lead can cross the placenta and enter the developing fetal brain. Lead is cleared from the blood and soft tissues with a half-life of 1 to 2 months and more slowly from the skeleton, with a half-life of years to decades. Approximately 70% of lead excretion occurs via the urine, with lesser amounts eliminated via the feces; scant amounts are lost through sweat, hair, and nails (Leggett, 1993; O'Flaherty, 1993).

The toxic effects of lead result from its interference with the physiologic actions of calcium, zinc, and iron, through the inhibition of certain enzymes, and through binding to ion channels and regulatory proteins. Additional mechanisms include generating reactive oxygen species and altering gene expression (ATSDR, 2007). Large amounts of lead in the body can cause anemia, kidney injury, abdominal pain, seizures, encephalopathy, and paralysis. Equilibrated blood lead levels (BLLs) after chronic intake are associated with certain toxic effects. BLLs and associated toxic effects differ in children and adults. For instance, BLLs near 10 µg/dL can affect blood pressure in adults and neurodevelopment in children (Bellinger, 2004; CDC, 1991; Nash et al., 2003; Schwartz, 1995; Staessen et al., 1995). In 1991, based on prospective population studies, the Centers for Disease Control and Prevention (CDC) established a BLL of 10

Urinary Lead (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.721** (.700-.742)	**.701** (.677-.725)	**1.11** (1.05-1.15)	**1.70** (1.62-1.85)	**2.38** (2.22-2.79)	2465
	01-02	**.639** (.603-.677)	**.635** (.588-.676)	**1.03** (.963-1.08)	**1.52** (1.43-1.61)	**2.03** (1.89-2.22)	2689
	03-04	**.632** (.603-.662)	**.622** (.594-.655)	**.979** (.920-1.03)	**1.49** (1.33-1.64)	**1.97** (1.73-2.26)	2558
Age group							
6-11 years	99-00	**1.17** (.975-1.41)	**1.06** (.918-1.22)	**1.55** (1.22-1.97)	**2.71** (1.67-4.66)	**4.66** (1.97-18.0)	340
	01-02	**.918** (.841-1.00)	**.870** (.800-.933)	**1.27** (1.12-1.43)	**2.33** (1.59-3.64)	**3.64** (1.89-5.56)	368
	03-04	**.926** (.812-1.06)	**.914** (.781-1.03)	**1.45** (1.17-1.72)	**2.14** (1.62-3.47)	**3.47** (2.19-5.31)	290
12-19 years	99-00	**.496** (.460-.535)	**.469** (.408-.508)	**.709** (.655-.828)	**1.11** (.981-1.28)	**1.65** (1.15-2.79)	719
	01-02	**.404** (.380-.428)	**.375** (.342-.400)	**.603** (.541-.702)	**.990** (.882-1.18)	**1.41** (1.07-1.63)	762
	03-04	**.432** (.404-.461)	**.404** (.383-.436)	**.623** (.551-.730)	**.938** (.828-1.06)	**1.23** (1.09-1.35)	725
20 years and older	99-00	**.720** (.683-.758)	**.712** (.667-.739)	**1.10** (1.02-1.18)	**1.69** (1.53-1.87)	**2.31** (2.15-2.62)	1406
	01-02	**.658** (.617-.703)	**.652** (.608-.702)	**1.05** (.992-1.11)	**1.51** (1.40-1.61)	**2.00** (1.85-2.19)	1559
	03-04	**.641** (.606-.679)	**.633** (.605-.670)	**.988** (.917-1.04)	**1.47** (1.28-1.63)	**1.94** (1.72-2.12)	1543
Gender							
Males	99-00	**.720** (.679-.763)	**.693** (.645-.734)	**1.10** (.992-1.22)	**1.68** (1.50-2.09)	**2.43** (2.15-3.03)	1227
	01-02	**.639** (.607-.673)	**.638** (.586-.686)	**1.01** (.957-1.08)	**1.55** (1.41-1.61)	**2.06** (1.88-2.43)	1334
	03-04	**.615** (.588-.644)	**.593** (.561-.639)	**.914** (.862-.977)	**1.44** (1.25-1.53)	**2.00** (1.71-2.28)	1281
Females	99-00	**.722** (.681-.765)	**.707** (.667-.746)	**1.11** (1.05-1.18)	**1.74** (1.50-2.02)	**2.38** (2.03-2.88)	1238
	01-02	**.639** (.594-.688)	**.625** (.571-.682)	**1.03** (.946-1.11)	**1.50** (1.39-1.61)	**1.98** (1.85-2.15)	1355
	03-04	**.648** (.601-.698)	**.649** (.604-.718)	**1.03** (.938-1.10)	**1.56** (1.34-1.73)	**1.96** (1.72-2.20)	1277
Race/ethnicity							
Mexican Americans	99-00	**.940** (.876-1.01)	**.887** (.796-1.03)	**1.43** (1.37-1.58)	**2.38** (2.08-2.77)	**3.46** (2.78-4.18)	884
	01-02	**.810** (.731-.898)	**.774** (.702-.893)	**1.29** (1.09-1.44)	**2.05** (1.75-2.50)	**2.78** (2.56-3.33)	682
	03-04	**.755** (.681-.838)	**.708** (.612-.851)	**1.18** (1.09-1.31)	**1.86** (1.50-2.26)	**2.31** (1.98-2.92)	618
Non-Hispanic blacks	99-00	**.722** (.659-.790)	**.671** (.583-.753)	**1.11** (.988-1.20)	**2.00** (1.56-2.51)	**2.83** (2.20-3.88)	568
	01-02	**.644** (.559-.742)	**.608** (.510-.710)	**.962** (.853-1.20)	**1.79** (1.36-2.33)	**2.75** (2.04-3.98)	667
	03-04	**.609** (.529-.701)	**.569** (.492-.698)	**.900** (.793-1.03)	**1.48** (1.11-1.97)	**2.24** (1.65-2.88)	723
Non-Hispanic whites	99-00	**.696** (.668-.725)	**.677** (.645-.718)	**1.07** (.997-1.14)	**1.66** (1.50-1.83)	**2.31** (1.94-2.82)	822
	01-02	**.615** (.579-.654)	**.621** (.571-.667)	**1.00** (.933-1.07)	**1.46** (1.37-1.52)	**1.88** (1.62-2.03)	1132
	03-04	**.623** (.592-.655)	**.618** (.587-.657)	**.971** (.914-1.03)	**1.44** (1.25-1.61)	**1.85** (1.64-2.10)	1074

µg/dL or higher as the level of concern in children. Recent studies have suggested that neurodevelopmental effects may occur at BLLs lower than 10 µg/dL (Canfield et al., 2003; Lanphear et al., 2000). Many animal studies have established the multiple neurotoxic effects of lead (ATSDR, 2007).

In occupationally exposed adults, subtle or nonspecific neurocognitive effects have been reported at BLLs as low as 20-30 µg/dL (Mantere et al., 1984; Schwartz et al., 2001), with overt encephalopathy, seizures, and peripheral neuropathy generally occurring at much higher levels (e.g., higher than 100-200 µg/dL). BLLs higher than 40 µg/dL can result in proximal tubular dysfunction and decreased glomerular filtration rate leading to interstitial and peritubular fibrosis when high body burdens persist. Low level environmental lead exposure may be associated with small decrements in renal function (Kim et al., 1996; Muntner et al., 2003; Payton et al., 1994). Results of studies of adults with either occupational or environmental lead exposure have shown consistent associations between increased BLLs and increased blood pressure (Nash et al., 2003; Schwartz, 1995; Staessen et al., 1995) and associations between increased bone lead concentrations and blood pressure (Hu et al., 1996; Korrick et al., 1999). High dose occupational lead exposure, usually with BLLs greater than 40 µg/dL, may alter sperm morphology, reduce sperm count, and decrease fertility (Alexander et al., 1996; Telisman et al., 2000). At low environmental exposures, lead in women may be associated with hypertension during pregnancy, premature delivery, and spontaneous abortion (Baghurst et al., 1987; Bellinger 2005; Borja-Aburto et al., 1999).

Workplace standards and guidelines for lead exposure and monitoring have been established by OSHA and ACGIH, respectively. Both drinking water and ambient air standards for lead have been established by the U.S. EPA. IARC considers inorganic lead compounds probable human carcinogens, and organic lead compounds not classifiable with respect to human carcinogenicity. NTP considers lead and its compounds reasonably anticipated to be human carcinogens. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Blood lead measurement is the preferred method of evaluating lead exposure and its human health effects. BLLs reflect both recent intake and equilibration with stored lead in other tissues, particularly in the skeleton. Urine levels may reflect recently absorbed lead, though there is greater individual variation in urine lead than in blood and greater potential for contamination.

The Adult Blood Lead Epidemiology and Surveillance program has tracked BLLs reported by states for mostly for occupational but also for non-occupational exposure in U.S. adult residents. Overall, the national prevalence rate for adults with BLLs 25 µg/dL or higher was 7.5 per 100,000 adults; the prevalence rate has declined annually since 1994 (CDC, 2006). A decrease in BLLs is evident also in adult NHANES results reported over past decades (CDC, 2005*a*). The U.S. adult population has similar or slightly lower BLLs than adults in other developed nations (CDC, 2005*b*). A general population survey of adults Germany in 1998 reported a geometric mean blood lead concentration of 3.07 µg/dL (Becker et al., 2002), almost double the geometric mean of 1.75 µg/dL in U.S. adults in the 1999-2000 NHANES sample. A general population survey of adults in Italy tested in 2000 found BLLs slightly more than double those reported for U.S. adults in the 1999-2000 NHANES sample (Apostoli et al., 2002a).

In NHANES 1999-2002 in children 1-5 years old, both the geometric mean (1.9 µg/dL) and percentage of children with BLLs greater than 10 µg/dL (1.6%) were lower than those from NHANES 1991-1994, when the geometric mean BLL was 2.7 µg/dL and 4.4% of children had BLLs of 10µg/dL or higher (CDC, 2005*b*; Pirkle et al., 1998). More recently, Jones et al (2009) showed that the prevalence of BLLs of 10 µg/dL or greater decreased from 8.6% in NHANES 1988-1991 to 1.4% in NHANES 1999-2004, which is an 84% decline. Temporal declines in children's BLLs have been found in other developed countries (Wilhelm et al., 2006). Surveillance data reported by U.S. state childhood lead programs also show a decline in the percentage of children younger than 6 years of age who had BLLs of 10 µg/dL or higher. Data submitted through state public health programs from 2006 showed that 1.21% of approximately 3.3 million children tested had BLLs of 10 µg/dL or higher (http://www.cdc.gov/nceh/lead/surv/database/State_Confirmed_byYear_1997_to_2006.xls). However, BLLs greater than 10 µg/dL continue to be more prevalent among children with known risk factors, including minority race or ethnicity; urban residence; residing in housing built before the 1950's; and low family income (CDC, 1991; CDC, 2002; Jones et al., 2009). For example, approximately 11,000 higher-risk children and adolescents who were tested from 2001 to 2002 at an urban medical center had higher BLLs than the NHANES sample; the geometric mean BLL was 3.2 µg/dL in males and 3.0 µg/dL in females (Soldin et al., 2003).

Biomonitoring studies on levels of lead provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of lead than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Mercury

CAS No. 7439-97-6

General Information

Mercury is a naturally occurring metal that has elemental (metallic), inorganic, and organic forms. Elemental mercury is a shiny, silver-white liquid (quicksilver) obtained predominantly from the refining of mercuric sulfide in cinnabar ore. Elemental mercury is used to produce chlorine gas and caustic soda for industrial applications. Other major uses include electrical equipment (e.g., thermostats and switches), electrical lamps, thermometers, sphygmomanometers and barometers, and dental amalgam. Inhalation of elemental mercury volatilized from dental amalgam is a major source of mercury exposure in the general population (Halbach, 1994; Kingman et al., 1998; Woods et al., 2007). Accidental spills of elemental mercury, which create an episodic potential for volatization and inhalation of mercury vapor, have often required public health intervention (Zeitz et al., 2002). Also, elemental mercury is used in rituals practiced in some Latin American and Caribbean communities.

Elemental mercury is released into the air from the combustion of fossil fuels (primarily coal), solid-waste incineration, and mining and smelting. Atmospheric elemental mercury can be deposited on land and water. In addition, water can be contaminated by the direct release of elemental and inorganic mercury from industrial discharges. Metabolism of mercury by microorganisms in aquatic sediments creates methyl mercury, an organic form of mercury, which can bioaccumulate in aquatic and terrestrial food chains. The ingestion of methyl mercury, predominantly from fish and other seafood, constitutes the main source of dietary mercury exposure in the general population. Apart from methyl mercury, synthetic organomercury compounds were once used in pharmaceutical applications, and mercury compounds are still used as preservatives (e.g., thimerosal, phenylmercuric acetate) or topical antiseptics (e.g., merbromin).

Inorganic mercury exists in two oxidative states (mercurous and mercuric) that combine with other elements, such as chlorine (e.g., mercuric chloride), sulfur, or oxygen, to form inorganic mercury compounds or salts. Inorganic mercury compounds such as mercuric oxide are used in producing batteries and pigments and in synthesizing many organic chemicals. Some cosmetic skin creams from countries other than the U.S. may contain inorganic mercury. Imported folk and alternative medicines occasionally are contaminated with inorganic mercury.

The kinetics of the different forms of mercury vary considerably. Poorly absorbed from the gastrointestinal tract, elemental mercury is absorbed mainly by inhaling volatilized vapor, and is distributed to most tissues, with the highest concentrations occurring in the kidneys (Barregard et al., 1999 ; Hursh et al., 1980; IARC, 1993). After elemental mercury is absorbed, it is oxidized in

Total Blood Mercury—2003-2004

Geometric mean and selected percentiles of blood concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.797** (.703-.903)	**.800** (.700-.900)	**1.70** (1.50-1.90)	**3.30** (2.90-3.90)	**4.90** (4.30-5.50)	8373
Age group							
1-5 years	03-04	**.326** (.285-.372)	**.300** (.300-.300)	**.500** (.500-.700)	**1.00** (.800-1.60)	**1.80** (1.30-2.50)	911
6-11 years	03-04	**.419** (.363-.484)	**.400** (.400-.500)	**.700** (.700-.900)	**1.30** (1.00-1.60)	**1.90** (1.40-3.50)	856
12-19 years	03-04	**.490** (.418-.574)	**.500** (.400-.600)	**1.00** (.800-1.20)	**1.80** (1.40-2.30)	**2.60** (2.10-3.30)	2081
20 years and older	03-04	**.979** (.860-1.12)	**1.00** (.800-1.10)	**2.00** (1.70-2.30)	**3.80** (3.20-4.40)	**5.40** (4.60-6.70)	4525
Gender							
Males	03-04	**.814** (.714-.927)	**.800** (.700-.900)	**1.80** (1.50-2.00)	**3.70** (3.20-4.30)	**5.40** (4.60-6.50)	4132
Females	03-04	**.781** (.689-.886)	**.800** (.700-.900)	**1.60** (1.40-1.80)	**3.00** (2.50-3.50)	**4.40** (3.60-5.30)	4241
Race/ethnicity							
Mexican Americans	03-04	**.563** (.472-.672)	**.600** (.500-.700)	**1.00** (.800-1.30)	**1.90** (1.60-2.40)	**3.00** (2.20-3.80)	2085
Non-Hispanic blacks	03-04	**.877** (.753-1.02)	**.900** (.800-1.00)	**1.60** (1.40-1.80)	**3.00** (2.30-4.00)	**4.40** (3.30-6.00)	2293
Non-Hispanic whites	03-04	**.776** (.655-.919)	**.800** (.700-.900)	**1.70** (1.40-2.00)	**3.20** (2.60-3.90)	**4.70** (4.00-5.60)	3478

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.2.

the tissues to mercurous and mercuric inorganic forms. Blood concentrations decline initially with a rapid half-life of approximately 1-3 days followed by a slower half-life of approximately 1-3 weeks (Barregard et al., 1992; Sandborgh-Englund et al., 1998). The slow-phase half-life may be several weeks longer in persons with chronic occupational exposure (Sallsten et al., 1993). After exposure to elemental mercury, excretion of mercury occurs predominantly through the kidney (Sandborgh-Englund et al., 1998), and peak urine levels can lag behind peak blood levels by days to a few weeks (Barregard et al., 1992); thereafter, for both acute and chronic exposures, urinary mercury levels decline with a half-life of approximately 1-3 months (Roels et al., 1991; Jonsson et al., 1999).

Less than 15% of inorganic mercury is absorbed from the human gastrointestinal tract (Rahola et al., 1973). Lesser penetration of inorganic mercury occurs through the blood-brain barrier than occurs with either elemental or methyl mercury (Hattula and Rahola, 1975; Vahter et al., 1994). The half-life of inorganic mercury in blood is similar to the slow-phase half-life of mercury after inhalation of elemental mercury. Excretion occurs by renal and fecal routes.

The fraction of methyl mercury absorbed from the gastrointestinal tract is about 95% (Aberg et al., 1969; Miettinen et al., 1971). Methyl mercury enters the brain and other tissues (Vahter et al., 1994) and then undergoes slow dealkylation to inorganic mercury. Human pharmacokinetic studies indicate that methyl mercury declines in blood and the whole body with a half-life of approximately 50 days, with most elimination occurring through in the feces (Sherlock et al., 1984; Smith et al., 1994; Smith and Farris, 1996). Methyl mercury is incorporated into growing hair, a measure of accumulated dose (Cernichiari et al., 1995; Suzuki et al., 1993), and a useful marker of exposure in epidemiologic studies (Grandjean et al., 1992 and 1999; McDowell et al., 2004; Myers et al., 2003).

Transplacental transport of methyl mercury and elemental mercury has been demonstrated in animals (Kajiwara et al., 1996; Vimy et al., 1990). Mercury levels in the cord blood are higher than in the mother's blood (Stern and Smith, 2003), and the newborn's levels decline gradually over several weeks (Bjornberg et al., 2005). Inorganic mercury and methyl mercury are distributed into human breast milk in relatively low concentrations; the transfer

Total Blood Mercury−1999-2002

Geometric mean and selected percentiles of blood concentrations (in µg/L) for males and females aged 1 to 5 years and females aged 16 to 49 years in the U.S. population, National Health and Nutrition Examination Survey, 1999-2002.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Age Group							
1-5 years (females and males)	99-00	**.343** (.297-.395)	**.300** (.200-.300)	**.500** (.500-.600)	**1.40** (1.00-2.30)	**2.30** (1.20-3.50)	705
	01-02	**.318** (.268-.377)	**.300** (.200-.300)	**.700** (.500-.800)	**1.20** (.900-1.60)	**1.90** (1.40-2.90)	872
Females	99-00	**.377** (.299-.475)	**.200** (.200-.300)	**.800** (.500-1.10)	**1.60** (1.00-2.80)	**2.70** (1.30-5.50)	318
	01-02	**.329** (.265-.407)	**.300** (.200-.300)	**.700** (.500-.800)	**1.30** (1.00-2.10)	**2.60** (1.30-4.90)	432
Males	99-00	**.317** (.269-.374)	**.200** (.200-.300)	**.500** (.500-.600)	**1.10** (.800-1.60)	**2.10** (1.10-3.50)	387
	01-02	**.307** (.256-.369)	**.300** (.200-.300)	**.600** (.400-.700)	**1.30** (.900-1.70)	**1.70** (1.40-2.00)	440
16-49 years (females only)	99-00	**1.02** (.825-1.27)	**.900** (.800-1.20)	**2.00** (1.50-3.00)	**4.90** (3.70-6.30)	**7.10** (5.30-11.3)	1709
	01-02	**.833** (.738-.940)	**.700** (.700-.800)	**1.70** (1.40-1.90)	**3.00** (2.70-3.50)	**4.60** (3.70-5.90)	1928
Race/ethnicity (females, 16-49 years)							
Mexican Americans	99-00	**.820** (.664-1.01)	**.900** (.700-1.00)	**1.40** (1.20-2.00)	**2.60** (2.00-3.60)	**4.00** (2.70-5.50)	579
	01-02	**.667** (.541-.824)	**.700** (.500-.800)	**1.10** (1.00-1.40)	**2.10** (1.70-3.00)	**3.50** (2.30-4.40)	527
Non-hispanic blacks	99-00	**1.35** (1.06-1.73)	**1.30** (1.10-1.70)	**2.60** (1.80-3.40)	**4.80** (3.30-6.60)	**5.90** (4.20-11.7)	370
	01-02	**1.06** (.871-1.29)	**1.10** (.800-1.20)	**1.80** (1.50-2.20)	**3.20** (2.20-3.90)	**4.10** (3.30-6.00)	436
Non-hispanic whites	99-00	**.944** (.726-1.23)	**.900** (.700-1.10)	**1.90** (1.30-3.30)	**5.00** (3.00-6.90)	**6.90** (4.50-12.0)	588
	01-02	**.800** (.697-.919)	**.800** (.700-.800)	**1.50** (1.30-2.00)	**3.00** (2.20-3.70)	**4.60** (3.30-6.80)	806

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.14 and 0.14.

may be more efficient for inorganic mercury (Grandjean et al., 1995; Oskarsson et al., 1996). Mercury levels in breast milk also decline in the weeks after birth (Bjornberg et al., 2005; Drexler and Schaller, 1998; Sakamoto et al., 2002; Sakamoto et al., 2004).

The health effects of mercury are diverse and can depend on the form of the mercury to which a person is exposed and the dose and the duration of exposure. Acute, high-dose exposure to elemental mercury vapor may cause severe pneumonitis. At levels below those that cause acute lung injury, overt signs and symptoms of chronic inhalation may include tremor, gingivitis, and neurocognitive and behavioral disturbances, particularly irritability, depression, short-term memory loss, fatigue, anorexia, and sleep disturbance (Bidstrup et al., 1951; Smith et al., 1970; Smith et al., 1983). Low-level exposure from dental amalgams has not been associated with neurologic effects in children or adults (Bates et al., 2004; Bellinger et al., 2006; DeRouen et al., 2006; Factor-Litvak et al., 2003). Occupational exposure to elemental mercury vapor has been associated with subclinical effects on biomarkers of renal dysfunction (Cardenas et al., 1993).

Inorganic mercury exposure usually occurs by ingestion. Large amounts may cause irritant or corrosive effects on the gastrointestinal tract (Sanchez-Sicilia et al., 1963). Once absorbed, the most prominent effect is on the kidneys where mercury accumulates and may lead to renal tubular necrosis. Acrodynia is a sporadic and predominantly pediatric syndrome historically associated with calomel (mercuric oxide) in teething powders and occasionally other inorganic forms of mercury. The constellation of findings may include anorexia, insomnia, irritability, hypertension, maculopapular rash, pain in the extremities, and pinkish discoloration of the hands and feet (Tunnessen et al., 1987).

Overt poisoning from methyl mercury primarily affects the central nervous system, causing parasthesias, ataxia, dysarthria, hearing impairment, and progressive constriction of the visual fields, typically after a latent period of weeks to months. High-level prenatal exposure may result in a constellation of developmental deficits that includes mental retardation, cerebellar ataxia, dysarthria, limb deformities, altered physical growth, sensory impairments, and cerebral palsy (NRC, 2000). In recent epidemiologic studies, lower levels of prenatal exposure due to maternal seafood consumption have been associated with an increased risk for abnormal neurocognitive test results in children (NRC, 2000; Rice, 2004). Although recent investigations have suggested a possible link between chronic ingestion of methyl mercury and an increased risk for cardiovascular disease, the existence of a causal relation is unresolved (Chan and Egeland, 2004; Rissanen et al., 2000; Salonen et al., 1995; Stern 2005; Vupputuri et al., 2005).

Workplace standards for inorganic mercury exposure have been established by OSHA and ACGIH, and a drinking water

Inorganic Blood Mercury

Geometric mean and selected percentiles of blood concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	.600 (.500-.600)	.700 (.700-.700)	8147
Age group							
1-5 years	03-04	*	< LOD	< LOD	< LOD	.500 (<LOD-.600)	792
6-11 years	03-04	*	< LOD	< LOD	< LOD	.600 (.500-.600)	842
12-19 years	03-04	*	< LOD	< LOD	.500 (<LOD-.500)	.600 (.500-.600)	2060
20 years and older	03-04	*	< LOD	< LOD	.600 (.500-.600)	.700 (.700-.800)	4453
Gender							
Males	03-04	*	< LOD	< LOD	.500 (.500-.600)	.600 (.600-.700)	4015
Females	03-04	*	< LOD	< LOD	.600 (.500-.600)	.700 (.700-.800)	4132
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	.500 (.500-.600)	.700 (.600-.800)	2007
Non-Hispanic blacks	03-04	*	< LOD	< LOD	.600 (.500-.600)	.700 (.600-.800)	2240
Non-Hispanic whites	03-04	*	< LOD	< LOD	.600 (.500-.600)	.700 (.600-.700)	3406

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.42.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

standard for inorganic mercury has been established by U.S. EPA. IARC considers methylmercury to be a possible human carcinogen and elemental and inorganic mercury to be unclassifiable with regard to human carcinogenicity. Information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA at: http://www.epa.gov/mercury and from ATSDR at: http://www.atsdr.cdc.gov/toxprofiles.

Biomonitoring Information

In the general population, the total blood mercury concentration is due mostly to the dietary intake of organic forms, particularly methyl mercury. Urinary mercury consists mostly of inorganic mercury (Cianciola et al., 1997; Kingman et al., 1998). These distinctions can help interpret mercury blood levels in people. Total blood mercury levels increase with greater fish consumption (Dewailly et al., 2001; Grandjean et al., 1995; Mahaffey et al., 2004; Sanzo et al., 2001; Schober et al., 2003). Urine mercury levels increase as more occlusal surfaces of teeth are filled with mercury-containing amalgams (Becker et al., 2003).

In Germany the geometric mean for blood mercury was 0.58 µg/L for 4645 adults, aged 18 to 69 years, who participated in a 1998 representative population survey (Becker et al., 2002). From 1996 through 1998, Benes et al. (2000) studied 1216 blood donors in the Czech Republic (896 men and 320 women, average age 33 years; 758 children, average age 9.9 years); the median concentration of blood mercury was 0.78 µg/L for adults and 0.46 µg/L for children. A cohort of 1127 U.S. military veterans (mean age 52.8 years, range 40 years to 78 years) had an average total blood mercury concentration of 2.55 µg/L. These men had no occupational exposure to mercury but previously had received dental amalgams at military facilities (Kingman et al., 1998).

Over the NHANES 1999-2006 survey periods, total blood mercury geometric mean levels in females aged 16-49 years did not change, although non-Hispanic black females had higher levels than non-Hispanic white or Mexican American females. Among the three racial/ethnic groups, total blood mercury increased with age, and the age-related changes differed across the groups (Caldwell et al., 2009). During the same survey periods, total blood mercury levels declined slightly in non-Hispanic black and Mexican American children, and increased slightly in non-Hispanic white children (Caldwell, et al., 2009). In NHANES 1999-2002, slightly higher total blood mercury levels were found in U.S. adult women in several ethnic subgroups (Hightower et al., 2006).

Clinically observable signs of ataxia and paresthesias may occur when blood mercury levels increase to approximately 100 µg/L after methyl mercury poisoning. However, the developing fetus may be the most susceptible to the effects of ongoing methyl mercury exposure (NRC, 2000). A cord blood mercury level of 85 µg/L (lower 95% confidence bound = 58 µg/L) is associated with a 5% increase in the prevalence of an abnormal Boston Naming Test (NRC,

Urinary Mercury—2003-2004

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.447** (.406-.492)	**.420** (.360-.480)	**1.00** (.870-1.14)	**2.08** (1.78-2.42)	**3.19** (2.76-3.55)	2538
Age group							
6-11 years	03-04	**.254** (.213-.304)	**.200** (.160-.250)	**.440** (.330-.580)	**1.16** (.610-1.61)	**1.96** (1.13-2.97)	287
12-19 years	03-04	**.358** (.313-.408)	**.330** (.290-.370)	**.700** (.530-.840)	**1.60** (1.14-2.52)	**2.93** (1.88-3.66)	722
20 years and older	03-04	**.495** (.442-.555)	**.480** (.410-.570)	**1.12** (.930-1.29)	**2.20** (1.85-2.65)	**3.33** (2.76-3.88)	1529
Gender							
Males	03-04	**.433** (.405-.463)	**.400** (.350-.460)	**.940** (.840-1.05)	**1.88** (1.63-2.18)	**2.68** (2.34-3.05)	1266
Females	03-04	**.460** (.396-.534)	**.430** (.330-.530)	**1.07** (.870-1.28)	**2.26** (1.77-2.90)	**3.54** (2.76-4.31)	1272
Race/ethnicity							
Mexican Americans	03-04	**.416** (.340-.509)	**.360** (.280-.430)	**.960** (.700-1.23)	**2.19** (1.39-3.24)	**3.16** (1.99-6.30)	619
Non-Hispanic blacks	03-04	**.476** (.413-.549)	**.430** (.360-.530)	**.890** (.770-1.00)	**1.96** (1.60-2.31)	**3.09** (2.03-4.89)	713
Non-Hispanic whites	03-04	**.441** (.382-.509)	**.420** (.330-.520)	**1.01** (.840-1.23)	**2.08** (1.67-2.46)	**3.24** (2.67-3.60)	1066

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.14.

2000). Levels in U.S. women of childbearing age have generally been much lower than these levels (CDC, 2005). ACGIH recommends that the blood levels due to inorganic mercury exposure in workers not exceed 15 µg/L. Blood mercury levels of women and children in NHANES 1999-2006 were also below levels established as occupational exposure guidelines (Caldwell, et al., 2009). Information about the biological exposure indices is provided here for comparison, not to imply a safety level for general population exposure.

Urinary mercury levels in recent German (Becker et al., 2003), Czech (Benes et al., 2002), and Italian (Apostoli et al., 2002) adult population surveys were similar to those in a U.S. representative sample of women aged 16-49 years reported in NHANES 1999-2006 (Caldwell, et al., 2009). In the study of U.S. military veterans with dental amalgams, mean urinary mercury was 3.1 µg/L. Urine mercury and the number of dental amalgams were correlated, and on average, the urine mercury increased by approximately 0.1 µg/L for each surface with a dental amalgam (Kingman et al., 1998). Recent studies in children with dental amalgams and urinary levels less than 5 µg/g of creatinine did not have changes in cognitive-behavioral testing when followed for 5-7 years (Bellinger et al., 2006; DeRouen et al., 2006). An expert-panel report recently prepared for the U.S. Department of Health and Human Services noted that several studies have observed a modest, reversible increase in urinary N-acetyl-glucosaminidase, a biomarker of perturbation in renal tubular function, among workers with urinary mercury concentrations of 25-35 µg/L or greater (Barregard et al., 1988; Langworth et al., 1992). The ACGIH (2007) currently recommends that urinary inorganic mercury in workers not exceed 35 µg/g of creatinine.

Finding a measurable amount of mercury in blood or urine does not mean that the level of mercury causes an adverse health effect. Biomonitoring studies provide physicians and public health officials with reference ranges so that they can determine whether people have been exposed to higher levels of mercury than are found in the general population. Biomonitoring data will also help scientists plan and conduct research on exposure and health effects.

Urinary Mercury (creatinine corrected)—2003-2004

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.443** (.404-.486)	**.447** (.392-.498)	**.909** (.785-1.00)	**1.65** (1.40-1.86)	**2.35** (1.88-2.85)	2537
Age group							
6-11 years	03-04	**.297** (.246-.358)	**.276** (.208-.347)	**.485** (.391-.630)	**1.25** (.667-1.79)	**1.79** (1.11-2.61)	286
12-19 years	03-04	**.255** (.225-.289)	**.217** (.196-.275)	**.464** (.376-.535)	**1.06** (.714-1.39)	**1.67** (1.13-2.03)	722
20 years and older	03-04	**.508** (.455-.566)	**.525** (.447-.616)	**1.00** (.875-1.09)	**1.76** (1.46-2.11)	**2.54** (2.04-3.00)	1529
Gender							
Males	03-04	**.365** (.333-.400)	**.362** (.309-.417)	**.696** (.620-.784)	**1.31** (1.18-1.44)	**1.87** (1.51-2.30)	1266
Females	03-04	**.532** (.472-.599)	**.545** (.455-.652)	**1.06** (.969-1.21)	**1.88** (1.64-2.30)	**2.77** (2.12-3.56)	1271
Race/ethnicity							
Mexican Americans	03-04	**.384** (.307-.480)	**.365** (.280-.455)	**.768** (.619-.990)	**1.62** (1.23-2.16)	**2.32** (1.78-4.01)	618
Non-Hispanic blacks	03-04	**.343** (.301-.391)	**.306** (.265-.368)	**.587** (.522-.687)	**1.28** (.964-1.63)	**2.13** (1.41-2.87)	713
Non-Hispanic whites	03-04	**.463** (.400-.537)	**.476** (.385-.588)	**.970** (.800-1.07)	**1.67** (1.32-2.11)	**2.40** (1.88-2.90)	1066

Urinary Mercury−Females Aged 16-49 Years Old, 1999-2002

Geometric mean and selected percentiles of urine concentrations (in µg/L) for females aged 16 to 49 years in the U.S. population, National Health and Nutrition Examination Survey, 1999-2002.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Age group (females)							
16-49 years	99-00	**.719** (.622-.831)	**.760** (.610-.910)	**1.62** (1.43-1.94)	**3.15** (2.55-3.92)	**5.00** (3.59-5.79)	1748
	01-02	**.606** (.553-.665)	**.580** (.500-.670)	**1.37** (1.23-1.55)	**2.91** (2.53-3.17)	**3.99** (3.50-4.63)	1960
Race/ethnicity (females, 16-49 years)							
Mexican Americans	99-00	**.724** (.656-.799)	**.650** (.560-.810)	**1.69** (1.45-2.07)	**3.68** (3.10-4.45)	**5.62** (4.91-7.38)	595
	01-02	**.592** (.502-.699)	**.560** (.420-.710)	**1.35** (1.09-1.76)	**2.84** (2.32-3.85)	**4.13** (2.81-6.24)	531
Non-Hispanic blacks	99-00	**1.06** (.832-1.35)	**1.03** (.850-1.51)	**2.30** (1.83-3.03)	**4.81** (3.41-6.18)	**6.98** (5.04-10.3)	381
	01-02	**.772** (.616-.966)	**.740** (.540-.930)	**1.76** (1.30-2.37)	**3.50** (2.57-4.97)	**5.18** (3.61-6.92)	442
Non-Hispanic whites	99-00	**.657** (.557-.774)	**.710** (.520-.870)	**1.50** (1.31-1.77)	**2.84** (2.39-3.32)	**4.05** (3.16-5.52)	594
	01-02	**.565** (.501-.637)	**.540** (.450-.650)	**1.31** (1.09-1.56)	**2.70** (2.22-3.16)	**3.62** (3.13-4.54)	826

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 01-02 are 0.14 and 0.14.

Urinary Mercury (creatinine corrected)−Females Aged 16-49 Years Old, 1999-2002

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for females aged 16 to 49 years in the U.S. population, National Health and Nutrition Examination Survey, 1999-2002.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Age group (females)							
16-49 years	99-00	**.710** (.624-.806)	**.723** (.636-.833)	**1.41** (1.24-1.65)	**2.48** (2.10-2.97)	**3.27** (2.85-3.92)	1748
	01-02	**.620** (.579-.664)	**.650** (.582-.709)	**1.27** (1.15-1.42)	**2.30** (2.07-2.45)	**3.00** (2.68-3.39)	1960
Race/ethnicity (females, 16-49 years)							
Mexican Americans	99-00	**.685** (.580-.809)	**.639** (.508-.790)	**1.45** (1.27-1.61)	**2.89** (2.21-3.42)	**4.51** (3.07-5.68)	595
	01-02	**.600** (.526-.686)	**.596** (.426-.709)	**1.32** (1.04-1.47)	**2.41** (2.14-2.77)	**3.21** (2.65-4.46)	531
Non-Hispanic blacks	99-00	**.658** (.520-.831)	**.615** (.475-.892)	**1.22** (.909-1.79)	**2.56** (1.69-3.99)	**3.99** (2.76-5.14)	381
	01-02	**.522** (.410-.665)	**.516** (.387-.664)	**1.03** (.742-1.47)	**1.97** (1.42-3.25)	**3.21** (1.87-4.44)	442
Non-Hispanic whites	99-00	**.706** (.605-.824)	**.721** (.631-.846)	**1.41** (1.23-1.72)	**2.46** (1.99-2.97)	**3.05** (2.46-4.00)	594
	01-02	**.632** (.578-.691)	**.655** (.569-.744)	**1.28** (1.14-1.45)	**2.30** (2.03-2.56)	**2.95** (2.45-3.53)	826

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Molybdenum

CAS No. 7439-98-7

General Information

Elemental molybdenum is a silver-white, hard metal widely used to add strength and hardness and retard corrosion in metal alloys. Compounds of molybdenum are also used as corrosion inhibitors, hydrogenation catalysts, lubricants, chemical reagents in hospital laboratories, and in pigments for ceramics, inks, and paints. More recently, semiconductor and battery industries have begun to use molybdenum. Molybdenum occurs in natural waters and may be present in concentrations of several hundred micrograms per liter or higher in ground and surface water near mining operations or ore deposits.

Molybdenum is a nutritionally essential trace element that enters the body primarily from dietary sources. In humans, molybdenum is a cofactor for three enzyme classes—sulfite oxidase, aldehyde dehydrogenase, and xanthine oxidase (Kisker et al., 1997). The recommended dietary allowance for adult men and women is 45 µg/day (IOM, 2001), and the average dietary daily intake of molybdenum is approximately 100 µg/day (IOM, 2001; WHO, 1996). Gastrointestinal absorption of molybdenum averages 88-93% for dietary intakes of 22-1490 µg/day. Excretion occurs predominantly via the kidneys, which exert homeostatic regulation over molybdenum balance. At a daily oral molybdenum dose of 24 µg, urinary excretion over six days

Urinary Molybdenum

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**45.9** (40.1-52.6)	**50.7** (44.6-58.4)	**84.9** (78.7-92.3)	**135** (125-146)	**180** (154-216)	2257
	01-02	**45.0** (42.1-48.0)	**52.4** (48.9-55.5)	**83.4** (79.1-88.7)	**124** (117-130)	**165** (145-176)	2690
	03-04	**39.7** (37.7-41.7)	**44.5** (41.6-46.7)	**78.5** (74.9-82.3)	**111** (105-118)	**138** (133-146)	2558
Age group							
6-11 years	99-00	**78.2** (61.0-100)	**84.8** (67.7-105)	**126** (106-147)	**178** (147-259)	**267** (159-840)	310
	01-02	**63.3** (53.4-75.0)	**69.2** (63.0-77.6)	**109** (94.5-124)	**169** (138-197)	**197** (161-291)	368
	03-04	**62.2** (56.7-68.3)	**71.3** (55.7-84.1)	**108** (92.7-122)	**138** (127-152)	**181** (138-235)	290
12-19 years	99-00	**54.3** (47.6-62.0)	**60.6** (52.2-70.3)	**93.3** (79.9-109)	**146** (112-171)	**188** (146-216)	648
	01-02	**60.6** (55.5-66.2)	**65.7** (58.7-73.1)	**97.1** (91.8-108)	**145** (129-159)	**179** (155-227)	762
	03-04	**52.5** (49.0-56.3)	**59.6** (55.5-65.1)	**87.3** (84.5-91.4)	**118** (105-125)	**143** (130-156)	725
20 years and older	99-00	**41.7** (36.7-47.4)	**46.6** (40.5-52.5)	**76.7** (73.4-82.2)	**126** (114-134)	**168** (143-206)	1299
	01-02	**41.1** (38.3-44.1)	**47.6** (43.7-51.2)	**79.1** (71.9-83.6)	**114** (103-124)	**150** (130-166)	1560
	03-04	**35.9** (34.0-38.0)	**40.3** (37.6-42.1)	**71.5** (67.3-75.2)	**105** (98.6-111)	**133** (119-144)	1543
Gender							
Males	99-00	**52.7** (45.7-60.7)	**57.5** (48.5-68.4)	**93.2** (83.8-106)	**150** (128-187)	**215** (161-278)	1121
	01-02	**51.0** (46.6-55.7)	**56.9** (52.0-62.6)	**88.5** (81.6-96.5)	**130** (120-141)	**169** (145-194)	1335
	03-04	**45.5** (43.3-47.8)	**51.0** (48.1-55.4)	**85.8** (82.8-90.7)	**119** (112-130)	**148** (136-163)	1281
Females	99-00	**40.4** (34.8-46.8)	**45.6** (40.4-52.0)	**77.3** (71.0-85.7)	**119** (105-138)	**154** (132-180)	1136
	01-02	**39.9** (37.2-42.9)	**45.8** (42.8-49.3)	**78.4** (72.6-82.9)	**115** (104-128)	**158** (130-177)	1355
	03-04	**34.9** (32.2-37.7)	**37.9** (33.5-41.6)	**67.3** (64.6-72.2)	**101** (97.3-108)	**127** (114-139)	1277
Race/ethnicity							
Mexican Americans	99-00	**47.0** (42.1-52.4)	**53.2** (49.2-59.0)	**80.6** (73.7-91.7)	**121** (103-139)	**152** (120-217)	780
	01-02	**49.3** (46.5-52.3)	**55.7** (50.4-61.0)	**86.4** (80.8-94.1)	**133** (113-155)	**177** (142-207)	683
	03-04	**47.0** (43.1-51.1)	**54.4** (48.2-59.9)	**82.9** (73.2-91.0)	**121** (106-143)	**152** (141-169)	618
Non-Hispanic blacks	99-00	**57.7** (51.0-65.2)	**62.2** (55.0-71.5)	**97.8** (85.0-110)	**153** (126-188)	**206** (150-274)	546
	01-02	**53.2** (49.9-56.7)	**60.3** (55.1-63.8)	**90.0** (81.0-101)	**132** (121-147)	**166** (147-170)	667
	03-04	**46.0** (41.7-50.8)	**46.2** (40.9-55.2)	**82.3** (73.3-91.3)	**117** (109-129)	**156** (135-175)	723
Non-Hispanic whites	99-00	**44.5** (37.0-53.4)	**48.5** (41.1-59.8)	**85.0** (76.7-96.5)	**135** (119-154)	**187** (146-223)	760
	01-02	**42.2** (38.5-46.2)	**48.9** (44.2-53.2)	**80.7** (71.9-85.8)	**117** (108-129)	**152** (134-180)	1132
	03-04	**37.1** (34.7-39.6)	**41.3** (38.1-44.5)	**75.2** (69.2-79.6)	**107** (99.3-115)	**130** (119-142)	1074

Limits of detection (LOD, see Data Analysis section) for survey years 99-00, 01-02, and 03-04 are 0.8, 0.8, and 1.5, respectively.

was 18% of the ingested dose; at daily oral doses of 95 µg and 428 µg, urinary excretion over six days rose to 50% and 67%, respectively, of the ingested dose (Turnlund et al., 1995). In industry, dust and other fine particles produced during refining or shaping of molybdenum or molybdenum-containing alloys are inhalational pathways of exposure.

Human health effects from molybdenum at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Molybdenum is generally considered to be of low human toxicity, and clinical or epidemiologic evidence of adverse effects is limited. Chronic exposure to very high levels may result in higher serum uric acid levels and a gout-like illness (Koval'skiy et al., 1961; U.S. EPA, 1993). Based on studies finding adverse reproductive effects in rats and mice, the Panel on Micronutrients of the Institute of Medicine identified a no observed adverse effect level (NOAEL) of 0.9 mg/kg/day and established a tolerable upper intake level of 0.03 mg/kg/day in humans (IOM, 2001). A long term inhalation bioassay of molybdenum trioxide in mice yielded "some evidence" of carcinogenicity (NTP, 1997). One case-control study suggested a possible link between occupational exposure to molybdenum and lung cancer (Droste et al., 1999), but available epidemiologic data are scant, and molybdenum has not been systematically evaluated for carcinogenicity by IARC.

Biomonitoring Information

Molybdenum is an essential element for health, and urinary levels reflect intake from all sources. Levels of molybdenum

Urinary Molybdenum (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**43.2** (40.0-46.6)	**41.6** (38.5-45.2)	**63.5** (59.3-68.8)	**108** (97.3-115)	**144** (125-171)	2257
	01-02	**42.5** (39.9-45.2)	**42.2** (40.1-45.2)	**62.0** (58.4-66.4)	**98.8** (90.1-109)	**130** (120-149)	2689
	03-04	**39.4** (37.6-41.3)	**39.2** (37.9-40.7)	**58.3** (55.6-61.5)	**89.0** (80.5-99.0)	**120** (107-135)	2558
Age group							
6-11 years	99-00	**85.9** (73.7-100)	**79.3** (71.6-88.4)	**122** (107-133)	**173** (130-243)	**214** (154-1040)	310
	01-02	**77.2** (73.1-81.5)	**77.6** (71.8-84.5)	**109** (99.4-120)	**159** (129-170)	**185** (165-219)	368
	03-04	**72.5** (65.2-80.7)	**73.5** (65.1-79.9)	**101** (84.9-117)	**132** (107-158)	**160** (129-257)	290
12-19 years	99-00	**41.9** (39.3-44.6)	**40.5** (37.7-44.4)	**57.3** (51.5-62.5)	**85.4** (67.4-107)	**112** (78.4-185)	648
	01-02	**43.4** (40.8-46.1)	**44.1** (40.8-47.2)	**60.8** (57.6-63.7)	**85.5** (79.7-93.8)	**106** (94.8-118)	762
	03-04	**37.5** (35.4-39.8)	**38.9** (36.9-41.8)	**53.2** (50.3-56.1)	**71.9** (64.6-76.9)	**81.0** (74.3-102)	725
20 years and older	99-00	**39.6** (36.9-42.6)	**38.5** (36.1-41.0)	**56.4** (53.5-60.7)	**92.5** (83.1-100)	**122** (116-147)	1299
	01-02	**39.3** (36.8-42.0)	**39.6** (36.4-42.1)	**57.2** (52.9-61.0)	**86.7** (75.2-96.8)	**123** (109-139)	1559
	03-04	**36.9** (35.0-38.9)	**37.0** (35.7-38.4)	**53.5** (50.0-56.9)	**79.8** (75.9-87.5)	**118** (101-134)	1543
Gender							
Males	99-00	**40.8** (37.5-44.3)	**38.5** (37.2-40.4)	**62.4** (55.9-68.4)	**101** (83.9-118)	**131** (112-179)	1121
	01-02	**40.3** (37.1-43.8)	**40.2** (36.3-43.3)	**60.5** (54.8-66.3)	**91.3** (83.4-106)	**123** (107-155)	1334
	03-04	**38.3** (36.1-40.7)	**37.8** (36.1-39.3)	**56.3** (53.3-59.3)	**85.7** (77.2-96.7)	**118** (100-139)	1281
Females	99-00	**45.5** (41.5-50.0)	**44.1** (39.5-48.8)	**64.4** (59.5-70.5)	**112** (95.2-121)	**152** (122-181)	1136
	01-02	**44.6** (42.2-47.1)	**45.1** (42.2-46.9)	**63.6** (59.5-69.4)	**107** (92.5-119)	**136** (117-169)	1355
	03-04	**40.5** (38.1-43.0)	**41.1** (38.7-43.7)	**61.4** (56.8-65.1)	**90.1** (82.2-103)	**122** (115-142)	1277
Race/ethnicity							
Mexican Americans	99-00	**42.9** (40.6-45.4)	**43.2** (40.9-45.6)	**61.6** (57.2-65.5)	**89.5** (80.0-103)	**115** (93.7-137)	780
	01-02	**48.1** (44.3-52.2)	**48.4** (44.8-52.3)	**71.7** (66.4-76.0)	**103** (90.0-120)	**129** (109-155)	682
	03-04	**43.5** (40.5-46.8)	**43.5** (41.0-46.2)	**62.8** (56.8-67.2)	**85.9** (79.5-97.0)	**112** (97.0-133)	618
Non-Hispanic blacks	99-00	**37.2** (33.4-41.6)	**37.1** (33.0-41.2)	**55.9** (49.6-63.3)	**88.2** (69.1-112)	**119** (88.3-141)	546
	01-02	**36.5** (34.1-39.0)	**37.5** (35.1-38.9)	**57.1** (49.7-62.4)	**78.3** (71.5-92.0)	**109** (81.1-127)	667
	03-04	**33.1** (30.5-35.9)	**31.7** (30.1-34.7)	**47.2** (43.7-52.1)	**72.9** (64.6-78.4)	**90.5** (78.4-118)	723
Non-Hispanic whites	99-00	**44.5** (40.2-49.2)	**42.1** (38.8-47.3)	**65.3** (58.9-71.3)	**116** (101-126)	**172** (131-195)	760
	01-02	**42.5** (39.3-46.0)	**41.9** (39.3-45.6)	**61.2** (57.1-67.2)	**104** (88.7-120)	**138** (120-163)	1132
	03-04	**39.1** (37.2-41.1)	**39.3** (37.7-40.8)	**58.1** (54.6-61.4)	**87.4** (78.9-96.7)	**118** (106-134)	1074

in urine for the U.S. population were well characterized in NHANES 1999-2000 and 2001-2002 (CDC, 2005); these levels were comparable to those reported for adults in smaller European population surveys (Iversen et al., 1998; Minoia et al., 2002; White and Sabbioni, 1998). Urinary molybdenum concentrations in infants may be slightly lower than those in other age groups (Sievers et al., 2001).

Finding a measurable amount of molybdenum in the urine does not mean that the level of molybdenum causes an adverse health effect. Biomonitoring studies on levels of molybdenum can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of molybdenum than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Platinum

CAS No. 7440-06-4

General Information

Platinum is a silver-gray, lustrous metal found naturally in extremely low amounts in the earth's crust and is typically associated with sulfide-ore bodies of nickel, copper, and iron. Important properties of platinum are resistance to corrosion, strength at high temperatures, and high catalytic activity. Platinum compounds are used in electrodes, jewelry, dental alloys, thick-film circuits printed on ceramic substrates, as oxidation catalysts in chemical manufacturing, and as drugs (e.g., cisplatin, carboplatin) in the treatment of cancer. Platinum-rhodium and platinum-palladium crystals are used as catalysts in petroleum refining and in vehicular catalytic converters to control exhaust emissions. Platinum-rhodium compounds are also used in glass and glass-fiber manufacture and in high-temperature thermocouples. Higher environmental soil concentrations of platinum from vehicular emissions have been found near roadways (Farago et al., 1998); however, the ambient air concentrations of platinum associated with its use in automotive engine catalytic converters are estimated to be thousands of times lower than occupational exposure limits.

Human health effects from platinum at low environmental

Urinary Platinum

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	2465
	01-02	*	< LOD	< LOD	< LOD	< LOD	2690
	03-04	*	< LOD	< LOD	< LOD	< LOD	2558
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	340
	01-02	*	< LOD	< LOD	< LOD	< LOD	368
	03-04	*	< LOD	< LOD	< LOD	< LOD	290
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	719
	01-02	*	< LOD	< LOD	< LOD	< LOD	762
	03-04	*	< LOD	< LOD	< LOD	< LOD	725
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1406
	01-02	*	< LOD	< LOD	< LOD	< LOD	1560
	03-04	*	< LOD	< LOD	< LOD	< LOD	1543
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	1227
	01-02	*	< LOD	< LOD	< LOD	< LOD	1335
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1238
	01-02	*	< LOD	< LOD	< LOD	< LOD	1355
	03-04	*	< LOD	< LOD	< LOD	< LOD	1277
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	884
	01-02	*	< LOD	< LOD	< LOD	< LOD	683
	03-04	*	< LOD	< LOD	< LOD	< LOD	618
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	568
	01-02	*	< LOD	< LOD	< LOD	< LOD	667
	03-04	*	< LOD	< LOD	< LOD	< LOD	723
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	822
	01-02	*	< LOD	< LOD	< LOD	< LOD	1132
	03-04	*	< LOD	< LOD	< LOD	< LOD	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.04, 0.04, and 0.07, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

doses or at biomonitored levels from low environmental exposures are unknown. Toxicity is determined by the type of compound (e.g., metallic, inorganic salt, or organometallic), route of exposure (e.g., intravenous medicinal use, inhalational, cutaneous, oral), and duration of exposure. Platinum metal is biologically inert, whereas soluble platinum compounds (e.g., halogenated salts) encountered in occupational settings can cause platinum salt hypersensitivity with symptoms that include bronchitis and asthma after inhalational exposure and contact dermatitis after skin exposure. Animals exposed to cholorplatinate salts used in industry have demonstrated severe hypersensitivity with asthma-like symptoms and anaphylactic shock (Parrot et al., 1969; Saindelle et al., 1969). Platinum metal and insoluble salts can produce eye irritation. When ingested or inhaled, platinum metal and insoluble salts are very poorly absorbed (<1% of a dose) and cleared from the body within a week after a single dose. Most absorbed platinum accumulates in the kidneys and is excreted in urine (Moore et al., 1975*a*, 1975*b*). The pharmaceutical cisplatin is an animal carcinogen and reasonably anticipated to be a human carcinogen as determined by NTP. The carcinogenicity of other platinum compounds remains uncertain. Workplace air standards for external exposure are established for soluble salts of platinum by OSHA and ACGIH, or recommended for the metal form by NIOSH (Czerczak and Gromiec, 2000). Information about external exposure (i.e., environmental levels) and health effects is available from

Urinary Platinum (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	2465
	01-02	*	< LOD	< LOD	< LOD	< LOD	2689
	03-04	*	< LOD	< LOD	< LOD	< LOD	2558
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	< LOD	340
	01-02	*	< LOD	< LOD	< LOD	< LOD	368
	03-04	*	< LOD	< LOD	< LOD	< LOD	290
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	719
	01-02	*	< LOD	< LOD	< LOD	< LOD	762
	03-04	*	< LOD	< LOD	< LOD	< LOD	725
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1406
	01-02	*	< LOD	< LOD	< LOD	< LOD	1559
	03-04	*	< LOD	< LOD	< LOD	< LOD	1543
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	1227
	01-02	*	< LOD	< LOD	< LOD	< LOD	1334
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1238
	01-02	*	< LOD	< LOD	< LOD	< LOD	1355
	03-04	*	< LOD	< LOD	< LOD	< LOD	1277
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	884
	01-02	*	< LOD	< LOD	< LOD	< LOD	682
	03-04	*	< LOD	< LOD	< LOD	< LOD	618
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	568
	01-02	*	< LOD	< LOD	< LOD	< LOD	667
	03-04	*	< LOD	< LOD	< LOD	< LOD	723
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	822
	01-02	*	< LOD	< LOD	< LOD	< LOD	1132
	03-04	*	< LOD	< LOD	< LOD	< LOD	1074

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

the International Programme on Chemical Safety at http://www.inchem.org/documents/ehc/ehc/ehc125.htm.

Biomonitoring Information

Urinary platinum levels reflect recent exposure. Levels of platinum in urine for the U.S. population were below the limit of detection (0.04 µg/L) in this *Report*. Several studies have shown that background concentrations in general populations were usually less than 0.005 µg/L (Iavicoli et al., 2004; Wilhelm et al., 2004) or less than 0.01 µg/L (Becker et al., 2003; Herr et al., 2003; Schierl et al., 1998).

One study found that traffic-control officers had no greater urinary platinum concentrations than office-based control subjects (Iavicoli et al., 2004). Gold-platinum dental restorations were correlated with increased urinary platinum concentrations, which elevate urinary platinum by five to twelve-fold (Begerow et al., 1999; Herr et al., 2003; Schierl, 2001). Platinum-industry and precious-metal workers had urinary concentrations about one-thousand times higher than general populations (Schierl et al., 1998). Modest (ten-fold or less) elevations in urinary platinum concentrations were associated with handling of cisplatin and carboplatin by pharmacy and other hospital personnel (Ensslin et al., 1997; Pethran et al., 2003).

Finding a measurable amount of platinum in the urine does not mean that the level of platinum causes an adverse health effect. Biomonitoring studies on levels of platinum provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of platinum than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Thallium

CAS No. 7440-28-0

General Information

Elemental thallium is a blue-white metal found in small amounts in soil and in sulfide-based minerals. In the past, thallium was obtained as a by-product of smelting other metals; however, it has not been specifically mined or refined in the United States since 1984. It is still used in relatively small amounts in pharmaceutical and electronics manufacturing, the latter being the current major industrial consumer of thallium in this country. In the United States, thallium has been restricted from use in rodenticides and depilatory cosmetics.

Thallium exposure occurs primarily from industrial processes such as coal-burning and smelting. From these and other sources, thallium is produced in a fine particulate form that can be absorbed through inhalation or ingestion. Thallium disappears from the blood with a half-life of several days, representing distribution into other tissues. In addition, thallium readily crosses the placenta and also distributes into breast milk. Elimination from the body tissues occurs slowly through urine and feces (Blanchardon et al., 2005).

Human health effects from thallium at low environmental

Urinary Thallium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.176** (.162-.192)	**.200** (.180-.220)	**.290** (.270-.330)	**.400** (.370-.420)	**.450** (.430-.480)	2413
	01-02	**.165** (.154-.177)	**.190** (.180-.200)	**.280** (.260-.290)	**.370** (.350-.390)	**.440** (.410-.470)	2653
	03-04	**.155** (.145-.165)	**.170** (.160-.180)	**.270** (.250-.290)	**.370** (.340-.400)	**.440** (.410-.490)	2558
Age group							
6-11 years	99-00	**.201** (.167-.243)	**.210** (.150-.280)	**.310** (.250-.350)	**.410** (.330-.450)	**.450** (.350-.590)	336
	01-02	**.172** (.147-.202)	**.200** (.160-.220)	**.290** (.230-.330)	**.350** (.340-.370)	**.390** (.360-.430)	362
	03-04	**.191** (.170-.215)	**.190** (.170-.230)	**.300** (.250-.370)	**.430** (.360-.500)	**.510** (.430-.690)	290
12-19 years	99-00	**.202** (.181-.225)	**.220** (.200-.240)	**.300** (.270-.340)	**.410** (.390-.430)	**.470** (.430-.510)	697
	01-02	**.200** (.182-.220)	**.220** (.190-.250)	**.310** (.290-.320)	**.370** (.350-.420)	**.470** (.400-.500)	746
	03-04	**.201** (.185-.218)	**.220** (.210-.240)	**.310** (.290-.320)	**.410** (.360-.470)	**.500** (.420-.560)	725
20 years and older	99-00	**.170** (.157-.183)	**.190** (.180-.210)	**.290** (.260-.320)	**.400** (.370-.420)	**.450** (.420-.480)	1380
	01-02	**.159** (.147-.173)	**.190** (.170-.200)	**.270** (.250-.290)	**.380** (.350-.400)	**.440** (.410-.490)	1545
	03-04	**.145** (.134-.156)	**.160** (.150-.170)	**.250** (.240-.270)	**.360** (.330-.390)	**.420** (.390-.460)	1543
Gender							
Males	99-00	**.197** (.179-.217)	**.220** (.200-.240)	**.320** (.280-.350)	**.400** (.370-.440)	**.450** (.420-.520)	1200
	01-02	**.184** (.173-.196)	**.210** (.200-.230)	**.290** (.280-.300)	**.380** (.360-.400)	**.430** (.400-.470)	1313
	03-04	**.167** (.156-.178)	**.190** (.180-.200)	**.280** (.260-.300)	**.370** (.340-.400)	**.430** (.400-.480)	1281
Females	99-00	**.159** (.145-.175)	**.180** (.150-.200)	**.270** (.250-.300)	**.390** (.350-.420)	**.460** (.410-.490)	1213
	01-02	**.149** (.137-.163)	**.160** (.150-.180)	**.260** (.230-.290)	**.370** (.330-.400)	**.440** (.400-.500)	1340
	03-04	**.144** (.133-.156)	**.160** (.140-.170)	**.250** (.230-.280)	**.370** (.330-.410)	**.450** (.410-.510)	1277
Race/ethnicity							
Mexican Americans	99-00	**.172** (.150-.196)	**.200** (.160-.230)	**.270** (.250-.300)	**.370** (.320-.420)	**.450** (.370-.520)	861
	01-02	**.160** (.148-.173)	**.180** (.160-.200)	**.260** (.240-.270)	**.340** (.310-.360)	**.400** (.350-.440)	675
	03-04	**.171** (.160-.183)	**.200** (.170-.220)	**.280** (.260-.310)	**.360** (.340-.420)	**.450** (.390-.480)	618
Non-Hispanic blacks	99-00	**.217** (.197-.239)	**.230** (.220-.260)	**.350** (.300-.390)	**.450** (.400-.520)	**.550** (.460-.630)	561
	01-02	**.202** (.187-.218)	**.220** (.200-.230)	**.300** (.270-.340)	**.410** (.380-.440)	**.520** (.440-.590)	657
	03-04	**.185** (.167-.206)	**.190** (.170-.220)	**.290** (.250-.330)	**.410** (.330-.490)	**.490** (.410-.640)	723
Non-Hispanic whites	99-00	**.170** (.153-.188)	**.200** (.170-.220)	**.290** (.260-.330)	**.400** (.360-.420)	**.450** (.420-.480)	801
	01-02	**.159** (.147-.172)	**.180** (.170-.200)	**.270** (.250-.290)	**.360** (.330-.390)	**.430** (.390-.460)	1114
	03-04	**.146** (.135-.158)	**.160** (.150-.170)	**.260** (.240-.280)	**.360** (.330-.380)	**.410** (.380-.460)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.02, 0.02, and 0.02, respectively.

doses or at biomonitored levels from low environmental exposures are unknown. Thallium produces toxicity by replacing intracellular potassium in the body, although additional mechanisms of action are possible. Severe accidental thallium poisonings from ingesting of rat poisons that contained water-soluble thallium salt have occurred. Relatively high-dose intentional or accidental ingestion can result in gastrointestinal symptoms followed by multi-organ failure, neurologic injury, and death. Peripheral neuropathy and alopecia are well-documented effects of acute and chronic exposures. Chronic high-level exposures have been associated with weight loss, arthralgias, and polyneuropathy. (ATSDR, 1992)

Workplace air standards and guidelines for external exposure are established by OSHA and ACGIH, respectively, and a drinking water standard has been established by U.S. EPA. IARC and NTP consider the evidence for the carcinogenicity of thallium as inadequate or unclassifiable. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Urinary thallium levels reflect recent exposure. Levels of thallium in urine for the U.S. population have been well characterized in NHANES 1999-2000 and 2001-2002

Urinary Thallium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.166** (.159-.173)	**.168** (.162-.176)	**.224** (.217-.233)	**.297** (.273-.319)	**.366** (.338-.387)	2413
	01-02	**.156** (.151-.162)	**.156** (.148-.164)	**.215** (.208-.222)	**.287** (.278-.300)	**.349** (.337-.365)	2652
	03-04	**.154** (.149-.158)	**.153** (.146-.160)	**.214** (.203-.222)	**.286** (.274-.304)	**.350** (.328-.369)	2558
Age group							
6-11 years	99-00	**.221** (.197-.248)	**.222** (.196-.236)	**.297** (.229-.356)	**.375** (.318-.469)	**.424** (.356-.600)	336
	01-02	**.211** (.198-.226)	**.207** (.198-.221)	**.286** (.260-.321)	**.370** (.333-.402)	**.412** (.389-.456)	362
	03-04	**.223** (.208-.238)	**.216** (.198-.229)	**.306** (.280-.346)	**.412** (.346-.458)	**.458** (.400-.532)	290
12-19 years	99-00	**.153** (.146-.160)	**.154** (.146-.162)	**.205** (.191-.219)	**.258** (.231-.278)	**.321** (.265-.364)	697
	01-02	**.143** (.137-.150)	**.145** (.135-.152)	**.196** (.184-.207)	**.272** (.250-.289)	**.312** (.299-.333)	746
	03-04	**.143** (.135-.152)	**.146** (.131-.155)	**.194** (.179-.208)	**.254** (.234-.280)	**.304** (.271-.327)	725
20 years and older	99-00	**.162** (.153-.171)	**.167** (.155-.176)	**.218** (.207-.230)	**.286** (.271-.300)	**.364** (.325-.389)	1380
	01-02	**.153** (.147-.159)	**.153** (.144-.161)	**.210** (.200-.217)	**.278** (.263-.293)	**.343** (.313-.362)	1544
	03-04	**.148** (.144-.153)	**.149** (.141-.156)	**.206** (.192-.215)	**.273** (.258-.289)	**.333** (.306-.353)	1543
Gender							
Males	99-00	**.154** (.147-.161)	**.156** (.149-.164)	**.202** (.192-.214)	**.269** (.254-.297)	**.338** (.300-.364)	1200
	01-02	**.146** (.140-.153)	**.148** (.142-.157)	**.192** (.184-.204)	**.260** (.246-.278)	**.307** (.291-.342)	1312
	03-04	**.140** (.135-.146)	**.142** (.134-.149)	**.188** (.180-.198)	**.264** (.235-.286)	**.317** (.287-.350)	1281
Females	99-00	**.178** (.167-.189)	**.182** (.169-.197)	**.244** (.226-.259)	**.317** (.281-.366)	**.380** (.333-.462)	1213
	01-02	**.167** (.158-.176)	**.167** (.153-.180)	**.233** (.217-.250)	**.313** (.282-.348)	**.378** (.348-.402)	1340
	03-04	**.167** (.162-.173)	**.166** (.157-.177)	**.235** (.222-.243)	**.313** (.286-.333)	**.368** (.340-.412)	1277
Race/ethnicity							
Mexican Americans	99-00	**.158** (.147-.170)	**.160** (.148-.176)	**.213** (.200-.237)	**.282** (.266-.304)	**.343** (.306-.389)	861
	01-02	**.156** (.145-.169)	**.155** (.145-.167)	**.204** (.191-.221)	**.286** (.250-.317)	**.361** (.301-.424)	674
	03-04	**.159** (.148-.170)	**.157** (.143-.172)	**.211** (.187-.241)	**.293** (.273-.324)	**.369** (.326-.422)	618
Non-Hispanic blacks	99-00	**.142** (.133-.152)	**.140** (.129-.151)	**.200** (.184-.214)	**.278** (.244-.307)	**.383** (.286-.462)	561
	01-02	**.138** (.128-.150)	**.136** (.125-.146)	**.194** (.170-.212)	**.256** (.238-.278)	**.328** (.271-.387)	657
	03-04	**.133** (.122-.145)	**.128** (.119-.143)	**.185** (.171-.200)	**.255** (.237-.269)	**.323** (.267-.377)	723
Non-Hispanic whites	99-00	**.169** (.160-.179)	**.173** (.167-.181)	**.227** (.215-.240)	**.300** (.272-.329)	**.364** (.333-.377)	801
	01-02	**.161** (.155-.167)	**.161** (.153-.171)	**.222** (.214-.231)	**.292** (.278-.304)	**.348** (.330-.383)	1114
	03-04	**.154** (.148-.160)	**.153** (.143-.162)	**.214** (.200-.223)	**.283** (.271-.304)	**.333** (.313-.363)	1074

(CDC, 2005) and are shown with results from NHANES 2003-2004 in this *Report*. These urine levels are generally comparable to levels observed in earlier studies of general populations (Brockhaus et al., 1981; Minoia et al., 1990; Paschal et al., 1998; Schaller et al., 1980; White and Sabbioni, 1998). Urinary concentrations of 100 µg/L in asymptomatic workers (500 times higher than median levels in the U.S. population) are thought to correspond to workplace exposures at the threshold limit value of 0.1 mg/m^3 (Marcus, 1985). Brockhaus et al. (1981) studied 1,265 people living near a thallium-emitting cement plant in Germany. Nearby residents were exposed by eating garden plants that had been contaminated by the thallium. Seventy-eight percent of the urine specimens in that study contained greater than 1 µg/L, with concentrations ranging up to 76.5 µg/L. There was no increase in the prevalence of symptoms at levels less than 20 µg/L and only a slight increase in nonspecific symptoms greater than 20 µg/L.

Finding a measurable amount of thallium in urine does not mean that the level of thallium causes an adverse health effect. Biomonitoring studies on levels of thallium provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of thallium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Tungsten

CAS No. 7440-33-7

General Information

Tungsten is a steel-gray to tin-white metal that occurs naturally in the earth's crust, mainly as scheelite ($CaWO_4$). Tungsten is used mainly for producing hard metals, which are used in rock drills and metal-cutting tools, and for producing ferrotungsten, which is used in the steel industry. Tungsten compounds are used as lubricating agents, filaments for incandescent lamps, bronzes in pigments, and as catalysts in the petroleum industry.

Most background environmental exposures to tungsten are from the soluble forms such as tungstate salts that may occur in drinking water. Occupational exposure is from dusts released during grinding or drilling of hard metals. Human health effects from tungsten at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Little information is available on the toxicity of tungsten. Although workers occupationally exposed to tungsten carbide may develop serious lung disease ("hard metal disease"), their illness may stem from exposure to cobalt mixed with tungsten carbide rather than to tungsten alone. Evidence is lacking for the carcinogenicity of tungsten, and it has not been classified with respect to its carcinogenicity by either IARC or NTP.

Urinary Tungsten

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.093** (.087-.100)	**.090** (.080-.090)	**.180** (.160-.190)	**.320** (.280-.370)	**.500** (.430-.550)	2338
	01-02	**.082** (.073-.092)	**.070** (.060-.090)	**.160** (.140-.180)	**.300** (.260-.350)	**.460** (.370-.560)	2652
	03-04	**.071** (.064-.078)	**.070** (.060-.080)	**.130** (.120-.140)	**.270** (.230-.300)	**.400** (.330-.480)	2558
Age group							
6-11 years	99-00	**.158** (.123-.204)	**.160** (.120-.220)	**.270** (.220-.350)	**.510** (.380-.560)	**.620** (.510-.950)	320
	01-02	**.137** (.110-.170)	**.140** (.110-.170)	**.260** (.200-.350)	**.460** (.360-.690)	**.770** (.510-1.53)	363
	03-04	**.130** (.111-.151)	**.140** (.120-.150)	**.240** (.190-.290)	**.410** (.290-.500)	**.500** (.370-.630)	290
12-19 years	99-00	**.113** (.097-.132)	**.110** (.090-.130)	**.210** (.180-.250)	**.360** (.310-.440)	**.530** (.380-.800)	679
	01-02	**.113** (.095-.135)	**.110** (.090-.130)	**.210** (.180-.260)	**.400** (.310-.520)	**.570** (.430-.790)	744
	03-04	**.105** (.090-.122)	**.100** (.090-.120)	**.190** (.160-.230)	**.350** (.290-.460)	**.530** (.350-1.00)	725
20 years and older	99-00	**.084** (.078-.091)	**.080** (.070-.090)	**.160** (.130-.180)	**.280** (.260-.320)	**.450** (.360-.520)	1339
	01-02	**.073** (.065-.082)	**.060** (.050-.070)	**.140** (.110-.160)	**.260** (.210-.310)	**.380** (.310-.490)	1545
	03-04	**.062** (.056-.068)	**.060** (.050-.070)	**.110** (.100-.120)	**.210** (.180-.250)	**.360** (.270-.430)	1543
Gender							
Males	99-00	**.107** (.096-.120)	**.100** (.090-.120)	**.210** (.190-.230)	**.390** (.310-.470)	**.530** (.470-.650)	1160
	01-02	**.088** (.074-.105)	**.080** (.060-.100)	**.170** (.140-.220)	**.330** (.260-.390)	**.490** (.380-.580)	1307
	03-04	**.081** (.071-.093)	**.080** (.070-.090)	**.140** (.130-.170)	**.300** (.250-.340)	**.430** (.340-.560)	1281
Females	99-00	**.082** (.077-.087)	**.070** (.060-.080)	**.150** (.130-.160)	**.270** (.240-.300)	**.400** (.320-.470)	1178
	01-02	**.076** (.069-.084)	**.060** (.060-.080)	**.150** (.120-.170)	**.280** (.230-.330)	**.430** (.340-.560)	1345
	03-04	**.062** (.056-.069)	**.060** (.050-.070)	**.110** (.100-.120)	**.220** (.190-.250)	**.370** (.270-.460)	1277
Race/ethnicity							
Mexican Americans	99-00	**.113** (.095-.133)	**.110** (.090-.130)	**.200** (.160-.250)	**.400** (.300-.520)	**.550** (.420-.830)	790
	01-02	**.101** (.093-.109)	**.100** (.090-.110)	**.190** (.170-.210)	**.370** (.310-.430)	**.570** (.450-.670)	680
	03-04	**.086** (.073-.100)	**.080** (.070-.100)	**.170** (.120-.220)	**.360** (.230-.620)	**.640** (.410-.800)	618
Non-Hispanic blacks	99-00	**.113** (.101-.126)	**.100** (.090-.130)	**.210** (.180-.250)	**.370** (.290-.460)	**.560** (.420-.810)	562
	01-02	**.096** (.080-.116)	**.090** (.070-.120)	**.160** (.130-.250)	**.310** (.270-.400)	**.460** (.400-.590)	649
	03-04	**.092** (.082-.104)	**.090** (.080-.110)	**.160** (.150-.180)	**.300** (.250-.330)	**.470** (.340-.550)	723
Non-Hispanic whites	99-00	**.092** (.084-.100)	**.080** (.070-.100)	**.180** (.160-.200)	**.320** (.270-.380)	**.470** (.380-.550)	802
	01-02	**.076** (.066-.088)	**.060** (.050-.080)	**.150** (.120-.180)	**.290** (.230-.360)	**.430** (.330-.620)	1117
	03-04	**.065** (.058-.073)	**.060** (.060-.070)	**.120** (.100-.130)	**.230** (.190-.290)	**.380** (.320-.410)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.04, 0.04, and 0.04, respectively.

Workplace air standards for external exposure have been established by ACGIH and recommended by NIOSH.

Biomonitoring Information

Levels of urinary tungsten reflect recent exposure. A nonrandom subsample from NHANES III demonstrated slightly higher values than those found in NHANES 1999-2000, 2001-2002, and 2003-2004 (Paschal et al., 1998), possibly due to methodologic, population, or exposure differences. A study of 14 unexposed adults yielded values similar to those in this *Report* (Schramel et al., 1997). In a Nevada community where tungsten was measured and found at increased levels in drinking water, the residents' median urinary levels were as much as 15-fold higher than median levels in the U.S. population (CDC, 2003, 2005).

Workers involved in grinding operations that released tungsten metal into the air had elevated urinary levels that were more than 900 times higher than the overall geometric mean of the U.S. population in the NHANES 1999-2000 (Kraus et al., 2001). Using neutron activation analysis to measure urinary tungsten, Nicolaou et al. (1987) found that a control group of non-metal workers had mean levels that were similar to the 95th percentiles in this *Report*, whereas the tungsten-worker group had mean urine levels 35 times higher. Patients with medically-inserted tungsten embolization coils showed elevated tungsten levels in

Urinary Tungsten (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.087** (.080-.095)	**.080** (.075-.086)	**.146** (.136-.158)	**.270** (.206-.333)	**.383** (.302-.459)	2338
	01-02	**.078** (.069-.087)	**.074** (.064-.084)	**.138** (.122-.154)	**.255** (.216-.300)	**.359** (.315-.436)	2651
	03-04	**.070** (.063-.078)	**.065** (.059-.074)	**.117** (.107-.133)	**.215** (.179-.253)	**.333** (.255-.439)	2558
Age group							
6-11 years	99-00	**.174** (.150-.201)	**.169** (.136-.198)	**.293** (.216-.333)	**.439** (.331-.667)	**.667** (.452-.880)	320
	01-02	**.168** (.144-.197)	**.158** (.139-.190)	**.275** (.231-.326)	**.412** (.333-.554)	**.634** (.436-1.28)	363
	03-04	**.151** (.131-.174)	**.144** (.119-.167)	**.250** (.205-.283)	**.333** (.278-.484)	**.484** (.333-.739)	290
12-19 years	99-00	**.084** (.078-.091)	**.079** (.074-.084)	**.138** (.124-.158)	**.231** (.180-.287)	**.339** (.237-.465)	679
	01-02	**.081** (.071-.092)	**.081** (.072-.091)	**.148** (.122-.167)	**.250** (.208-.301)	**.359** (.272-.431)	744
	03-04	**.075** (.065-.086)	**.071** (.061-.082)	**.122** (.098-.148)	**.197** (.167-.308)	**.379** (.197-.582)	725
20 years and older	99-00	**.080** (.072-.089)	**.075** (.067-.082)	**.130** (.116-.146)	**.218** (.179-.301)	**.347** (.245-.426)	1339
	01-02	**.070** (.063-.079)	**.067** (.058-.075)	**.119** (.099-.139)	**.216** (.176-.267)	**.333** (.253-.431)	1544
	03-04	**.063** (.057-.071)	**.059** (.053-.065)	**.105** (.094-.117)	**.181** (.155-.215)	**.279** (.217-.370)	1543
Gender							
Males	99-00	**.083** (.074-.094)	**.073** (.063-.086)	**.146** (.126-.165)	**.279** (.198-.386)	**.439** (.329-.605)	1160
	01-02	**.071** (.060-.083)	**.065** (.056-.077)	**.125** (.098-.153)	**.255** (.203-.306)	**.364** (.300-.431)	1306
	03-04	**.068** (.059-.079)	**.062** (.054-.071)	**.111** (.098-.133)	**.216** (.170-.284)	**.341** (.240-.500)	1281
Females	99-00	**.091** (.085-.098)	**.084** (.080-.091)	**.145** (.136-.158)	**.265** (.200-.301)	**.339** (.300-.381)	1178
	01-02	**.085** (.077-.094)	**.083** (.075-.091)	**.143** (.130-.161)	**.258** (.216-.317)	**.353** (.317-.538)	1345
	03-04	**.072** (.065-.079)	**.069** (.063-.078)	**.121** (.108-.138)	**.211** (.176-.237)	**.333** (.261-.439)	1277
Race/ethnicity							
Mexican Americans	99-00	**.106** (.093-.120)	**.100** (.086-.116)	**.184** (.152-.214)	**.329** (.267-.392)	**.497** (.354-.727)	790
	01-02	**.098** (.090-.108)	**.089** (.081-.100)	**.164** (.143-.187)	**.294** (.258-.375)	**.555** (.410-.797)	679
	03-04	**.079** (.065-.096)	**.073** (.054-.093)	**.136** (.103-.197)	**.300** (.233-.426)	**.482** (.344-.823)	618
Non-Hispanic blacks	99-00	**.073** (.064-.083)	**.071** (.061-.081)	**.124** (.109-.154)	**.201** (.188-.222)	**.360** (.217-.465)	562
	01-02	**.066** (.056-.077)	**.060** (.049-.079)	**.109** (.090-.125)	**.199** (.153-.285)	**.340** (.250-.414)	649
	03-04	**.066** (.059-.074)	**.067** (.055-.075)	**.105** (.095-.120)	**.186** (.150-.224)	**.317** (.214-.358)	723
Non-Hispanic whites	99-00	**.091** (.083-.100)	**.082** (.077-.088)	**.150** (.136-.169)	**.279** (.200-.354)	**.385** (.302-.462)	802
	01-02	**.078** (.068-.088)	**.073** (.061-.085)	**.139** (.121-.157)	**.253** (.209-.308)	**.353** (.286-.453)	1117
	03-04	**.069** (.060-.078)	**.063** (.057-.071)	**.116** (.104-.133)	**.199** (.167-.237)	**.299** (.222-.439)	1074

blood, urine, and hair (Bachthaler et al., 2004). Urinary tungsten levels in many patients were hundreds-fold higher than observed in this *Report*.

Finding a measurable amount of tungsten in the urine does not mean that the level of tungsten causes an adverse health effect. Biomonitoring studies on levels of tungsten provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of tungsten than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Uranium

CAS No. 7440-61-1

General Information

Uranium is a silver-white metal that is extremely dense and weakly radioactive. It usually occurs as an oxide and is extracted from ores containing less than 1% natural uranium. Natural uranium is a mixture of three isotopes: ^{238}U (greater than 99%), ^{235}U (about 0.72%), and ^{234}U. Uranium has many commercial uses, including nuclear weapons, nuclear fuel, in some ceramics, and as an aid in electron microscopy and photography. Depleted uranium (DU) refers to uranium in which the proportions of ^{235}U and ^{234}U isotopes have been reduced compared with the proportion in natural uranium. Since the 1990's, DU has been used by the military in armor-piercing ammunition and as a component of protective armor for tanks.

Variable concentrations of uranium occur naturally in drinking water sources. Thus, the primary exposure sources for nonoccupationally exposed persons are dietary (especially root vegetables) and drinking water. In workplaces that involve uranium mining, milling, or processing, human exposure occurs primarily by inhaling dust and other small particles. Exposure to DU may occur in military personnel from retention internal shrapnel that contains DU or exposure to dust generated from ammunition

Urinary Uranium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.008** (.007-.009)	**.007** (.006-.008)	**.013** (.010-.017)	**.027** (.021-.038)	**.046** (.037-.056)	2464
	01-02	**.009** (.007-.010)	**.008** (.007-.009)	**.014** (.012-.018)	**.030** (.023-.039)	**.046** (.034-.062)	2690
	03-04	**.008** (.007-.008)	**.007** (.006-.007)	**.011** (.010-.013)	**.021** (.017-.026)	**.031** (.026-.037)	2557
Age group							
6-11 years	99-00	**.009** (.007-.011)	**.007** (.006-.009)	**.013** (.009-.022)	**.032** (.019-.048)	**.048** (.033-.066)	340
	01-02	**.008** (.007-.010)	**.008** (.006-.010)	**.014** (.010-.020)	**.026** (.020-.036)	**.040** (.025-.049)	368
	03-04	**.008** (.007-.009)	**.007** (.006-.009)	**.012** (.009-.016)	**.020** (.016-.026)	**.028** (.020-.039)	289
12-19 years	99-00	**.009** (.008-.011)	**.009** (.008-.010)	**.015** (.012-.018)	**.026** (.020-.043)	**.044** (.028-.072)	719
	01-02	**.010** (.008-.012)	**.010** (.008-.012)	**.017** (.013-.023)	**.030** (.022-.042)	**.042** (.027-.088)	762
	03-04	**.010** (.009-.011)	**.009** (.008-.010)	**.015** (.012-.018)	**.028** (.023-.036)	**.038** (.036-.053)	725
20 years and older	99-00	**.008** (.006-.009)	**.007** (.005-.008)	**.013** (.010-.017)	**.027** (.021-.040)	**.046** (.036-.056)	1405
	01-02	**.009** (.007-.010)	**.008** (.007-.009)	**.014** (.012-.017)	**.031** (.022-.040)	**.046** (.034-.065)	1560
	03-04	*	**.006** (.005-.007)	**.011** (.009-.012)	**.019** (.016-.026)	**.029** (.024-.038)	1543
Gender							
Males	99-00	**.009** (.008-.011)	**.008** (.007-.010)	**.015** (.012-.021)	**.036** (.024-.046)	**.053** (.040-.067)	1227
	01-02	**.009** (.008-.011)	**.009** (.007-.010)	**.015** (.013-.021)	**.033** (.024-.045)	**.047** (.035-.065)	1335
	03-04	**.008** (.007-.009)	**.007** (.006-.008)	**.013** (.011-.016)	**.023** (.019-.027)	**.031** (.027-.035)	1280
Females	99-00	**.007** (.006-.008)	**.006** (.005-.007)	**.012** (.009-.015)	**.023** (.016-.033)	**.036** (.026-.050)	1237
	01-02	**.008** (.007-.010)	**.008** (.006-.009)	**.014** (.011-.017)	**.027** (.019-.037)	**.041** (.029-.063)	1355
	03-04	*	**.006** (.005-.007)	**.010** (.009-.011)	**.018** (.013-.027)	**.031** (.022-.039)	1277
Race/ethnicity							
Mexican Americans	99-00	**.017** (.012-.023)	**.016** (.011-.021)	**.033** (.020-.054)	**.060** (.040-.127)	**.114** (.054-.279)	883
	01-02	**.013** (.010-.016)	**.012** (.009-.016)	**.022** (.017-.030)	**.040** (.031-.054)	**.055** (.046-.069)	683
	03-04	**.014** (.011-.017)	**.013** (.009-.018)	**.024** (.017-.034)	**.041** (.028-.073)	**.064** (.039-.158)	618
Non-Hispanic blacks	99-00	**.009** (.007-.011)	**.008** (.006-.010)	**.014** (.010-.020)	**.028** (.018-.049)	**.052** (.030-.067)	568
	01-02	**.008** (.007-.009)	**.008** (.007-.009)	**.012** (.011-.015)	**.021** (.017-.027)	**.030** (.023-.037)	667
	03-04	**.008** (.008-.009)	**.007** (.007-.008)	**.012** (.011-.013)	**.021** (.017-.027)	**.031** (.023-.045)	722
Non-Hispanic whites	99-00	**.007** (.006-.009)	**.007** (.006-.007)	**.012** (.009-.016)	**.023** (.017-.037)	**.043** (.027-.051)	822
	01-02	**.008** (.007-.009)	**.007** (.006-.009)	**.013** (.011-.016)	**.026** (.019-.035)	**.037** (.029-.050)	1132
	03-04	*	**.006** (.005-.007)	**.010** (.009-.012)	**.018** (.015-.023)	**.027** (.020-.036)	1074

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.004, 0.004, and 0.005, respectively.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

impact.

Soluble forms of uranium salts are poorly absorbed in the gastrointestinal tract. Depending upon the specific compound and solubility, 0.1%-6% of an ingested dose may be absorbed. Inhaled uranium-containing particles are retained in the lungs, where limited absorption occurs (less than 5%). In cases of retained DU shrapnel, the shrapnel acts as a source of chronic, low level exposure. After long term or repeated exposure, kidneys, liver, and bones can accumulate uranium with the largest amounts being stored in bones (Li et al., 2005). Uranium is eliminated in feces and urine; about 50% of the absorbed dose is eliminated in the urine within the first 24 hours. After exposure to soluble uranium salts, the initial half-life of uranium is about 15 days (Bhattacharyya et al., 1992), which represents distribution and excretion, with much slower elimination from bone. After inhalation, the half-life of insoluble uranium in the lungs is several years (Durakovic et al., 2003).

Human health effects from uranium at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Radiation risks from exposure to natural uranium are very low. Health effects from uranium exposure result from chemical toxicity to the kidney, which can occur occasionally from high occupational exposure. Studies of persons with chronic exposure to soluble uranium salts in drinking water have not shown kidney

Urinary Uranium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**.007** (.006-.009)	**.007** (.006-.009)	**.013** (.010-.016)	**.024** (.019-.030)	**.034** (.027-.053)	2464
	01-02	**.008** (.007-.010)	**.007** (.006-.009)	**.014** (.011-.018)	**.026** (.020-.034)	**.040** (.028-.058)	2689
	03-04	**.008** (.007-.008)	**.007** (.006-.008)	**.012** (.010-.014)	**.021** (.017-.025)	**.029** (.023-.039)	2557
Age group							
6-11 years	99-00	**.009** (.007-.012)	**.008** (.006-.011)	**.015** (.010-.024)	**.030** (.016-.044)	**.037** (.030-.077)	340
	01-02	**.010** (.008-.011)	**.010** (.008-.012)	**.015** (.013-.019)	**.027** (.018-.032)	**.033** (.027-.048)	368
	03-04	**.009** (.008-.010)	**.008** (.007-.010)	**.013** (.011-.017)	**.024** (.016-.039)	**.033** (.022-.050)	289
12-19 years	99-00	**.007** (.006-.008)	**.006** (.005-.008)	**.010** (.009-.014)	**.020** (.014-.030)	**.030** (.019-.074)	719
	01-02	**.007** (.006-.008)	**.007** (.006-.008)	**.012** (.009-.016)	**.020** (.015-.026)	**.026** (.020-.042)	762
	03-04	**.007** (.006-.008)	**.006** (.005-.007)	**.010** (.008-.013)	**.019** (.015-.027)	**.034** (.022-.041)	725
20 years and older	99-00	**.007** (.006-.009)	**.007** (.006-.009)	**.013** (.010-.016)	**.024** (.019-.029)	**.034** (.025-.051)	1405
	01-02	**.008** (.007-.010)	**.007** (.006-.009)	**.014** (.011-.019)	**.027** (.020-.039)	**.043** (.030-.063)	1559
	03-04	*	**.007** (.006-.008)	**.012** (.010-.014)	**.020** (.017-.024)	**.028** (.022-.038)	1543
Gender							
Males	99-00	**.007** (.006-.009)	**.006** (.005-.008)	**.011** (.009-.015)	**.021** (.017-.028)	**.035** (.024-.056)	1227
	01-02	**.007** (.006-.008)	**.007** (.006-.008)	**.012** (.010-.015)	**.022** (.018-.028)	**.033** (.025-.047)	1334
	03-04	**.007** (.006-.008)	**.006** (.006-.007)	**.010** (.009-.012)	**.019** (.015-.024)	**.026** (.019-.039)	1280
Females	99-00	**.008** (.007-.010)	**.007** (.006-.010)	**.013** (.010-.017)	**.025** (.019-.033)	**.034** (.027-.054)	1237
	01-02	**.009** (.008-.011)	**.009** (.007-.011)	**.016** (.012-.021)	**.029** (.021-.042)	**.045** (.031-.067)	1355
	03-04	*	**.008** (.007-.009)	**.013** (.011-.016)	**.022** (.018-.028)	**.031** (.025-.041)	1277
Race/ethnicity							
Mexican Americans	99-00	**.015** (.011-.022)	**.015** (.011-.020)	**.029** (.016-.058)	**.059** (.027-.146)	**.100** (.042-.270)	883
	01-02	**.012** (.010-.016)	**.012** (.009-.016)	**.021** (.015-.028)	**.033** (.024-.053)	**.050** (.034-.080)	682
	03-04	**.013** (.010-.016)	**.013** (.009-.017)	**.022** (.016-.029)	**.035** (.026-.051)	**.051** (.034-.061)	618
Non-Hispanic blacks	99-00	**.006** (.004-.007)	**.005** (.004-.006)	**.008** (.006-.013)	**.017** (.011-.029)	**.028** (.018-.048)	568
	01-02	**.005** (.005-.006)	**.005** (.005-.006)	**.008** (.007-.010)	**.013** (.011-.014)	**.017** (.014-.029)	667
	03-04	**.006** (.005-.006)	**.005** (.005-.006)	**.009** (.008-.009)	**.013** (.012-.015)	**.018** (.014-.024)	722
Non-Hispanic whites	99-00	**.007** (.006-.009)	**.007** (.006-.009)	**.012** (.010-.015)	**.021** (.017-.027)	**.030** (.024-.050)	822
	01-02	**.008** (.007-.009)	**.007** (.006-.009)	**.013** (.011-.016)	**.025** (.018-.032)	**.034** (.025-.051)	1132
	03-04	*	**.007** (.006-.008)	**.011** (.010-.013)	**.019** (.015-.024)	**.027** (.020-.040)	1074

* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

injury associated with elevated urinary uranium levels (Kurttio et al., 2006; McDiarmid et al., 2006). IARC and NTP have no ratings for uranium human carcinogenicity.

Workplace air standards and guidelines for external exposure to soluble and insoluble uranium compounds have been established by OSHA and ACGIH, respectively. Drinking water and other environmental standards have been established by U.S. EPA. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: [http://www.atsdr.cdc.gov/toxpro2.html.](http://www.atsdr.cdc.gov/toxpro2.html)

Biomonitoring Information

Levels of urinary uranium reflect recent and accumulated exposure. A previous nonrandom subsample from NHANES III (n = 499) (Ting et al., 1999) and other small populations have shown urinary concentrations that are similar to those in NHANES 1999-2000, 2001-2002, and 2003-2004 (Dang et al.,1992; Galletti, 2003; Karpas et al.,1996; Tolmachev et al., 2006). Older studies have demonstrated urinary uranium concentrations that are consistent with levels in the U.S. population, in that the levels were below their respective detection limits (Byrne et al., 1991; Hamilton et al., 1994; Komaromy-Hiller et al., 2000). In a study of 105 persons exposed to natural uranium in well water, urinary levels of uranium were as high as 9.55 µg/L (median 0.162 µg/L) (Orloff et al., 2004). Eighty-five percent of those levels were above the 95th percentile of the NHANES 1999-2000 population. In two studies of a Finnish population with high natural uranium concentrations in their drinking water, the median urinary concentration was 0.078 µg/L (ranging up to 5.65 µg/L), and no consistent effects on multiple endpoints of kidney function were found. (Kurttio et al., 2002, 2006).

The U.S. Nuclear Regulatory Commission (NRC) has set an action level of 15 µg/L urinary uranium to protect people who are occupationally exposed (U.S. NRC, 1978). Recent studies of veterans have been conducted to examine concerns about DU exposure during military conflicts. A cohort of 46 U.S. soldiers evaluated before, during, and after deployment had geometric mean urinary uranium concentrations that were less than the NHANES 1999-2000 and 2001-2002 geometric means at all three time periods, although slightly increased during and after deployment, (May et al., 2004). In 17 U.S. soldiers who had been injured and had embedded DU shrapnel for as long as eight years, the median urinary uranium concentration was 2.61 µg/g creatinine. In the same study, 28 soldiers who may have been exposed to DU by inhalation, ingestion, or wound contamination, but in whom no shrapnel was embedded, had a mean urinary uranium concentration of 0.066 µg/g creatinine (Gwiazda et al., 2004). In a much larger study of 446 Gulf War veterans who were concerned about past exposure to DU, the geometric mean urinary uranium concentration was 0.011 µg/L (McDiarmid et al., 2004). Follow up of 32 veterans with embedded shrapnel showed that increased urinary uranium levels persisted more than 12 years after the first exposure (McDiarmid et al., 2006). Six workers in a depleted uranium program showed concentrations of 0.110 to 45 µg/L (Ejnik et al., 2000). Urinary uranium measurements in 103 Canadian military personnel showed mean urinary levels slightly less than geometric mean in this *Report* (Ough et al., 2002).

Finding a measurable amount of uranium in urine does not mean that the level of uranium causes an adverse health effect. Biomonitoring studies on levels of uranium provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of uranium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Perchlorate

CAS No. 7601-90-3

General Information

Perchlorate is an inorganic chemical containing one chlorine and four oxygen atoms. It is normally found and produced as the anion of a sodium, potassium, or ammonium salt. Perchlorate is stable under most environmental and physiological conditions, but has strong oxidant properties in the presence of concentrated acids, certain catalytic metals, and reducing agents. The ammonium salt of the perchlorate ion has been manufactured in the military defense and aerospace industries primarily for use as an oxidizer in solid propellant systems for rockets and missiles. Other manufactured uses include fireworks, matches, and limited applications in pharmaceutics, laboratory analysis, leather tanning, fabric dyeing, and electroplating. In addition, small amounts of perchlorate can form naturally in the atmosphere (Dasgupta et al., 2006) and accumulate in nitrate-rich mineral deposits mined for use in fertilizers (Urbansky, 2002).

Perchlorate was added to the U.S. EPA's Contaminant Candidate List (CCL) for drinking water in 1998 following discoveries of its presence in drinking water supplies throughout the southwestern United States (U.S.EPA, 1998). Perchlorate has been characterized as a mobile and persistent ground and surface water contaminant. Drinking water, milk, and certain plants with high water content (e.g., lettuce) can be the main sources of intake for humans (FDA, 2007). Perchlorate is excreted unchanged from the human body with an estimated elimination half-life of about 7.5 hours and has a small estimated volume of distribution (Crump and Gibbs, 2005).

Animal and human studies have shown that perchlorate can inhibit thyroid hormone production (NAS, 2005). Large doses of perchlorate have been used as a medicine to treat hyperthyroidism and to diagnose disorders related to thyroid or iodine metabolism. Inhibition of iodine uptake by competition for the sodium/iodide symporter in the thyroid can be estimated in humans by measuring radioiodine uptake

Urinary Perchlorate

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**3.54** (3.29-3.81)	**3.70** (3.50-4.00)	**6.30** (5.80-6.90)	**10.0** (9.10-11.0)	**14.0** (11.0-17.0)	2820
	03-04	**3.22** (2.93-3.55)	**3.30** (2.90-3.80)	**5.50** (5.00-6.40)	**9.50** (8.40-11.0)	**13.0** (12.0-15.0)	2522
Age group							
6-11 years	01-02	**4.93** (4.22-5.76)	**5.20** (4.40-6.40)	**8.10** (6.90-9.80)	**12.0** (9.30-19.0)	**19.0** (12.0-23.0)	374
	03-04	**4.32** (3.67-5.09)	**4.60** (4.00-5.20)	**7.90** (5.70-9.50)	**13.0** (8.81-16.0)	**16.0** (11.0-29.0)	314
12-19 years	01-02	**3.80** (3.44-4.20)	**4.40** (3.80-4.80)	**6.80** (6.30-7.30)	**10.0** (8.90-11.0)	**13.0** (11.0-17.0)	828
	03-04	**3.62** (3.19-4.12)	**3.80** (3.20-4.40)	**6.40** (5.50-7.10)	**9.80** (7.90-12.0)	**13.0** (10.0-18.0)	721
20 years and older	01-02	**3.35** (3.08-3.65)	**3.50** (3.20-3.70)	**5.90** (5.30-6.60)	**10.0** (8.70-11.0)	**13.0** (11.0-17.0)	1618
	03-04	**3.05** (2.75-3.38)	**3.20** (2.70-3.60)	**5.20** (4.70-6.10)	**9.10** (7.90-10.0)	**12.0** (11.0-14.0)	1487
Gender							
Males	01-02	**4.19** (3.93-4.46)	**4.40** (4.20-4.60)	**7.10** (6.40-7.90)	**11.0** (9.70-12.0)	**14.0** (11.0-19.0)	1335
	03-04	**3.75** (3.39-4.16)	**3.90** (3.40-4.40)	**6.40** (5.60-7.50)	**11.0** (9.20-12.0)	**14.0** (13.0-17.0)	1229
Females	01-02	**3.01** (2.74-3.31)	**3.10** (2.70-3.40)	**5.40** (5.00-6.00)	**9.20** (8.20-11.0)	**13.0** (11.0-17.0)	1485
	03-04	**2.79** (2.49-3.11)	**2.90** (2.50-3.20)	**4.90** (4.40-5.50)	**8.20** (6.90-9.84)	**11.0** (8.80-15.0)	1293
Race/ethnicity							
Mexican Americans	01-02	**4.02** (3.47-4.66)	**4.40** (3.70-5.00)	**7.10** (5.80-8.40)	**12.0** (9.40-13.0)	**14.0** (12.0-18.0)	708
	03-04	**3.76** (3.45-4.11)	**3.96** (3.50-4.40)	**6.20** (5.30-7.50)	**11.0** (9.10-12.0)	**15.0** (12.0-17.0)	617
Non-Hispanic blacks	01-02	**3.51** (3.07-4.03)	**3.70** (3.10-4.10)	**5.90** (5.10-7.00)	**9.20** (7.80-12.0)	**15.0** (11.0-20.0)	681
	03-04	**3.21** (2.90-3.56)	**3.20** (2.87-3.50)	**5.40** (4.60-6.30)	**8.60** (7.50-11.0)	**13.0** (9.30-17.0)	652
Non-Hispanic whites	01-02	**3.51** (3.18-3.88)	**3.70** (3.40-4.10)	**6.30** (5.70-7.10)	**10.0** (8.90-11.0)	**14.0** (11.0-18.0)	1228
	03-04	**3.26** (2.89-3.68)	**3.30** (2.80-4.00)	**5.60** (4.90-6.80)	**9.40** (8.10-11.0)	**13.0** (11.0-15.0)	1092

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.05 and 0.05.
2001-2002 performed on surplus samples (variable unavailable of NHANES website)

inhibition (RUI). Short term human studies of the effect of perchlorate on RUI have been used for risk estimation (Greer et al., 2002; Lawrence et al. 2001, 2002; NAS, 2005; U.S.EPA, 2005). In these small short-term experimental studies on males and studies of male perchlorate workers with doses or estimated exposures thousands-fold higher than known environmental exposures, up to 68% RUI has been demonstrated, but without effects on serum levels of thyroid stimulating hormone or thyroxine (Braverman et al., 2005; Greer et al., 2002). However, in a representative sample of U.S. women with urinary levels of iodine less than 100 micrograms per day, urinary perchlorate at environmental exposure levels were inversely associated with thyroxine levels and positively associated with levels of thyroid stimulating hormone (Blount et al., 2006; Steinmaus et al., 2007).

During gestation and infancy, it is known that maternal and congenital hypothyroidism adversely effects neurological development and decreases learning capability. In the U.S., congenital hypothyroidism is a condition for which nearly all newborn blood is screened. Ecologic studies from screening programs with elevated perchlorate in the regional drinking water have indicated no increased prevalence of abnormal neonatal screening tests for this disorder in these regions (Kelsh et al., 2003; Lamm and Doemland, 1999; Li et al., 2000). Also, altered thyroid function was not found in Chilean pregnant women or their newborns with mean urinary perchlorate levels about 40-fold higher than average U.S. levels, although iodine intake was higher than U.S. levels and sufficient in most participants (Tellez et al., 2005). Many factors may be important in consideration of perchlorate action on the thyroid: dose; dietary iodine intake; gender; age; menopausal status; chronicity of exposure; and the presence of other substances known to affect thyroid function (e.g., nitrate, thiocyanate, medications).

Though it produces follicular cell thyroid tumors in animal studies at goitrogenic doses, perchlorate is negative in most genotoxic assays (U.S.EPA, 2005), suggesting its tumorgenic effect is a result of a chronic increase in thyroid stimulating hormone indirectly resulting from iodine uptake inhibition. Follicular cell thyroid tumors would

Urinary Perchlorate (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**3.56** (3.34-3.80)	**3.39** (3.18-3.66)	**5.61** (5.29-6.00)	**9.36** (8.19-10.3)	**12.7** (11.0-14.3)	2818
	03-04	**3.14** (2.89-3.41)	**3.00** (2.80-3.30)	**4.90** (4.50-5.30)	**8.40** (7.20-9.50)	**12.0** (11.0-14.0)	2504
Age group							
6-11 years	01-02	**5.71** (5.22-6.25)	**5.83** (5.19-6.25)	**8.33** (7.41-9.74)	**13.1** (11.1-16.0)	**17.5** (13.1-22.6)	374
	03-04	**5.24** (4.61-5.96)	**5.10** (4.70-5.50)	**7.20** (6.40-10.0)	**13.0** (8.90-20.0)	**20.0** (11.0-44.0)	313
12-19 years	01-02	**2.95** (2.64-3.29)	**2.89** (2.56-3.39)	**4.50** (3.97-5.26)	**7.12** (6.60-8.10)	**9.87** (7.46-13.4)	827
	03-04	**2.70** (2.45-2.98)	**2.70** (2.50-3.00)	**4.20** (3.70-4.50)	**6.30** (5.10-7.50)	**8.00** (6.90-11.0)	715
20 years and older	01-02	**3.46** (3.20-3.73)	**3.26** (3.04-3.58)	**5.37** (4.93-5.91)	**9.09** (7.61-10.2)	**12.3** (10.1-14.3)	1617
	03-04	**3.03** (2.76-3.32)	**2.90** (2.60-3.20)	**4.70** (4.30-5.10)	**8.10** (6.90-9.40)	**11.0** (9.60-15.0)	1476
Gender							
Males	01-02	**3.40** (3.20-3.60)	**3.25** (3.04-3.47)	**5.35** (4.93-5.86)	**8.80** (7.52-9.87)	**11.4** (10.1-13.0)	1335
	03-04	**3.07** (2.81-3.35)	**2.90** (2.70-3.20)	**4.80** (4.30-5.30)	**7.30** (6.50-9.70)	**12.0** (9.70-15.0)	1220
Females	01-02	**3.72** (3.39-4.09)	**3.60** (3.20-4.10)	**5.99** (5.33-6.67)	**10.0** (8.15-12.1)	**13.4** (11.4-16.0)	1483
	03-04	**3.21** (2.87-3.59)	**3.10** (2.80-3.40)	**5.00** (4.60-5.60)	**8.90** (7.00-11.0)	**12.0** (9.90-15.0)	1284
Race/ethnicity							
Mexican Americans	01-02	**3.77** (3.22-4.40)	**3.51** (3.02-4.44)	**6.05** (4.93-7.64)	**10.4** (8.37-13.0)	**14.4** (11.6-17.4)	708
	03-04	**3.42** (3.16-3.70)	**3.30** (3.00-3.50)	**5.40** (4.60-6.10)	**9.20** (7.60-11.0)	**13.0** (11.0-19.0)	616
Non-Hispanic blacks	01-02	**2.53** (2.24-2.87)	**2.54** (2.12-2.84)	**4.08** (3.51-4.93)	**6.87** (5.93-8.43)	**10.1** (8.33-12.2)	680
	03-04	**2.22** (2.00-2.45)	**2.10** (1.90-2.30)	**3.40** (3.10-3.90)	**6.20** (4.60-8.00)	**8.50** (6.60-11.0)	648
Non-Hispanic whites	01-02	**3.76** (3.46-4.08)	**3.54** (3.22-4.02)	**5.82** (5.44-6.25)	**9.52** (8.30-10.5)	**12.8** (11.3-14.6)	1227
	03-04	**3.35** (2.99-3.75)	**3.20** (2.90-3.50)	**5.10** (4.60-5.60)	**8.80** (7.20-10.0)	**12.0** (10.0-17.0)	1080

2001-2002 performed on surplus samples (variable unavailable of NHANES website) be unlikely to occur without overt perturbation of thyroid homeostasis. Additional information about exposure and health effects is available from the U.S.EPA at: http://www.epa.gov/safewater/ccl/perchlorate/perchlorate.html and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Urinary perchlorate levels reflect recent exposure. Blount et al. (2007) analyzed a subsample of NHANES 2001-2002 which demonstrated detectable perchlorate in all urinary samples and showed slightly higher levels in children as compared to adults. When these NHANES 2001-2002 urinary levels of perchlorate are used to calculate daily oral intakes for the U.S. population, most of the population is considered to be below the U.S. EPA reference dose (Blount et al., 2007). The levels seen in NHANES 2003-2004 show a similar pattern to NHANES 2001-2002. Compared to a previous study of pregnant women in three Chilean communities with varying perchlorate levels in the drinking water, the women in the community with the highest drinking water levels had mean urinary perchlorate levels about 40 times greater than the geometric mean for participants in NHANES 2001-2002 aged 20 years and older (Tellez et al., 2005). Also, the 95^{th} percentile of NHANES 2001-2002 participants aged 20 years and older have urinary perchlorate levels that are several thousand times less than urinary levels measured during occupational exposure of perchlorate workers (Braverman et al., 2005).

Finding a measurable amount of perchlorate in urine does not mean that the level of perchlorate causes an adverse health effect. Biomonitoring studies of urinary perchlorate provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of perchlorate than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Perfluorochemicals

General Information

The perfluorochemicals (PFCs) are molecules in which all bonds of the alkyl chain are carbon-fluorine bonds except for the terminal functional group. Discussed here are perfluoroalkyl acids, amides, and alcohols which are by-products, end products, or processing aids used in the synthesis of fluoropolymers. Fluoropolymers have applications in waterproofing and protective coatings of clothes, furniture, and other products; and also as constituents of floor polish, adhesives, fire retardant foam, and insulation of electrical wire. A major application of one important fluoropolymer, polytetrafluoroethylene, has been the heat-resistant non-stick coatings used on cooking ware and other protected surfaces. Because of their properties, fluoropolymer products are used in a wide range of industries including aerospace, automotive, building/construction, chemical processing, electrical and electronics, semiconductor, and textiles. There are many other fluorocarbon type chemicals which are not addressed here, such as perfluorochemical telomers, finalized perfluorochemical polymer products, chlorofluorocarbons and investigational blood substitutes.

Perfluorooctanoic acid (PFOA) has been manufactured since the 1950s, primarily as its ammonium salt, as a solubilization aid in the synthesis of polytetrafluoroethylene. PFOA is usually not a residual contaminant in non-stick surfaces made of polytetrafluoroethylene. Worldwide annual production of PFOA was estimated to be 260 metric tons in 1999 (Prevedouros et al., 2006). Production rates and emission rates have fallen since 2002 after conversion to a new synthesis process. Other perfluoroalkyl carboxylates of various chain lengths were also formed in the process used prior to 2002. However, current manufacturing practices reduce the formation of these by exclusively using fluorotelomers (Prevedouros et al., 2006).

Perfluorooctanesulfonyl fluoride (POSF) was synthesized as a polymerization starting material. POSF-based polymers have been used in a wide variety of products such as waterproofing, textiles, and fire protection. Other PFCs (including small amounts of PFOA) can also form as side-reaction by-products in the synthesis of POSF (e.g., perfluorooctane sulfonamide, PFOSA), or form as degradation products during its reaction to create the intermediate reacting monomers, N-methylperfluorooctanesulfonamidoethanol (MeFOSE) and N-ethylperfluorooctanesulfonamidoethanol (EtFOSE), or form in the final product (e.g., perfluorooctane sulfonate, PFOS) (Hekster et al., 2003; Olsen et al., 2005; U.S. EPA, 2003). MeFOSE and EtFOSE have been used in food packaging and textile treatments, and their oxidation products, N-methylperfluorooctane-sulfonamidoacetic acid (Me-PFOSA-AcOH) and N-ethylperfluorooctanesulfonamidoacetic acid (Et-PFOSA-AcOH), respectively, may be markers of food or consumer exposures. In addition, several pathways (during manufacturing) can lead to formation of PFOS or other sulfonyl-containing PFCs as residual contaminants in the final polymer products. Perfluorohexane sulfonate (PFHxS) has also been used to synthesize the fluoropolymers used in firefighting foams and some carpet treatments. U.S. manufacture of POSF-based products began ending in about 2000. Global production that year for POSF materials was 3700 metric tons (Prevedouros et al., 2006). Perfluorononanoic acid (PFNA) was an impurity in the process that produces PFOS.

The PFCs have limited water solubility, low volatility (as salts or ionized) and can remain in the environment and bioconcentrate in animals (e.g., some fish bioconcentrate

Perfluorinated Chemicals in this *Report*

Perfluorinated Compounds	CAS number	Abbreviation
Serum Perfluorobutane Sulfonic Acid		PFBuS
Serum Perfluorodecanoic Acid	335-76-2	PFDeA
Serum Perfluorododecanoic Acid	307-55-1	PFDoA
Serum Perfluoroheptanoic Acid	375-85-9	PFHpA
Serum Perfluorohexane Sulfonic Acid	355-46-4	PFHxS
Serum Perfluorononanoic Acid	375-95-1	PFNA
Serum Perfluorooctanoic Acid	335-67-1	PFOA
Serum Perfluorooctane Sulfonic Acid	1763-23-1	PFOS
Serum Perfluorooctane Sulfonamide	754-91-6	PFOSA
Serum 2-(*N*-Ethyl-Perfluorooctane sulfonamido) Acetic Acid		Et-PFOSA-AcOH
Serum 2-(*N*-Methyl-perfluorooctane sulfonamido) Acetic Acid		Me-PFOSA-AcOH
Serum Perfluoroundecanoic Acid	2058-94-8	PFUA

PFOS greater than 2000-fold over aquatic levels). PFOS and PFOA levels in archived bird eggs from Sweden have increased thirtyfold from 1968 to 2003 (Holmstrom et al., 2005). PFCs have been identified in surface coastal and ocean waters (Yamashita et al., 2005), in a wide variety of marine and land animals (Kannan et al., 2005; Keller et al., 2005; Taniyasu et al., 2003), and in human blood and semen (Calafat et al., 2006*a*; Guruge et al., 2005; Kannan et al., 2004; Olsen et al., 2003*a* and 2004*a*). In some cases, environmental breakdown products of the telomers used to make fluoropolymers or the metabolic products of fluorochemicals in the body can produce PFCs that are measured human blood. For instance, the 8-2 telomer, heptadecafluoro-1-decanol, may metabolize or degrade to PFOA (Dinglasan et al., 2004). It is unclear if environmentally degraded telomer products are a major source of other PFCs.

All sources of human exposure are uncertain, but probably include dietary sources (Kannan et al., 2004; Prevedouros et al., 2006; Tittlemier et al., 2007). PFOA (and probably other perfluoroalkyl acids) exist in the anionic state at physiologic and environmental pHs and their distribution in the body is determined, in part, by high protein binding in plasma and other proteins. Unlike many organohalogen contaminant chemicals, the perfluoroalkyl acids (PFOA and PFOS) do not tend to accumulate in fat tissue, but still can have long residence times in the body. PFOA is mostly excreted in the urine in animal studies, but limited observations in humans suggest that only one-fifth of the total body clearance is renal (Harada et al., 2005). The elimination half-life of PFOA in humans is roughly estimated to be 3.5 years and for PFOS, approximately 4.8 years (Olsen et al., 2007*a*). Excepting PFOS and PFOA, there is limited information on the sources, environmental fate, human toxicokinetics, or effects of other PFCs. The PFCs often measured in human serum are listed in the table.

Human health effects from PFCs at low environmental doses or at biomonitored levels from low environmental exposures are unknown. The ammonium salt of PFOA has been tested at high doses in mammalian animal studies and produced altered weights of the liver, kidney, thymus and spleen; hepatotoxicity; endocrine and immune effects; and in offspring, growth retardation and delayed sexual maturation (Kennedy et al., 2004; Lau et al., 2004; U.S. EPA, 2003). Both PFOA and perfluorodecanoic acid have been shown to reduce androgen levels in laboratory animal studies (Biegel et al., 1995; Bookstaff et al., 1990). PFOA preparations used in many studies may also contain a small percentage of other chain length perfluoroalkyl acids (i.e., C5, C6, C7). The liver toxicity of several PFCs is evident by vacuolization and lipid accumulation in both rodent and monkey livers (Seacat et al., 2002; Lau et al., 2004) and may be attributable to the ability of PFCs to affect intracellular lipid binding proteins, peroxisomal proliferation, and β-oxidation of lipids (Kudo et al., 2000, 2003; Vanden Heuvel et al., 1993). Some of the effects in animals may be mediated through peroxisomal proliferation, including immunologic effects and tumor induction, but the relevance of peroxisomal pathways in humans is unclear (Kennedy et al., 2004). PFOA has been reported to cause liver, pancreas,

Serum Perfluorobutane sulfonic acid (PFBuS)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2094
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	640
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1454
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1053
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	485
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	538
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

and testicular tumors in high dose animal testing (Biegel et al., 2001; Cook et al., 1992; Kennedy et al., 2004). Effects on serum liver enzymes in limited observational studies of human occupational exposures are unclear. Two recent cross-sectional human studies observed a negative correlation of birth weight with serum levels of PFOA (Apelberg et al., 2007; Fei et al., 2007).

Due to marked intergender differences in the elimination of PFOA in rats and substantial differences in the half-life of PFOA in rats, monkeys, and humans, the potential to estimate risks to humans from animal doses is uncertain. However, animal and human serum PFOA levels have been compared: serum levels associated with toxic effects in animals are 66-11,108 times higher than background serum levels in humans (Butenoff et al., 2004; U.S. EPA, 2003). A study of workers chronically exposed to primarily PFOA showed no biochemical evidence of hepatotoxicity or hormonal changes (adrenal, reproductive, thyroidal), and there was no clear evidence of excess all-cause or disease-specific mortality, or increased cancer rates (Alexander et al., 2003; Olsen et al., 1999; U.S. EPA, 2003).

Serum PFOS levels associated with toxicity in test animals were 310-1550 fold higher than 95 percent of the levels found in a study of adults (Olsen et al., 2003*a*, 2005). Animal studies of PFOS have demonstrated weight loss, hepatotoxicity, and changes in thyroid hormone concentrations (Grasty et al., 2003; Thibodeaux et al., 2003; Lau et al., 2004). At doses causing maternal toxicity, developmental and teratogenic effects were demonstrated in offspring. At high but non-toxic maternal doses of PFOS, development in offspring was stunted and hypothyroxinemia was observed. Late gestational exposure to PFOS in animal studies has also demonstrated early neonatal lethality, possibly related to lung immaturity (Lau et al., 2003). PFOA, PFOS, and other PFCs have not been classified as to human carcinogenicity by IARC or NTP.

Biomonitoring Information

Serum levels of PFCs (particularly PFOA and PFOS) tend to reflect cumulative exposure over several years. Twelve different PFCs were measured in the sera of NHANES 2003-2004 participants. Roughly similar levels of PFCs in serum have also been measured previously in other samples of the U.S. population. In such studies, PFOS, PFOA, perfluorohexanesulfonate (PFHxS), and perfluorononanoic acid (PFNA) are detectable in a high percentage of the participants and PFOS levels are generally 3-10 times higher than PFOA levels (Calafat et al., 2007*a*, 2007*b*; Olsen et al., 2003*a*, 2005). Analysis of the NHANES 2003-2004 subsample demonstrated higher levels of PFOA and PFOS in males and a slight increase in levels of PFOS with age (Calafat et al., 2007*b*). Slightly higher levels of PFOS and PFOA in males than females have been noted in several other studies (Calafat et al., 2007*a*; Harada et al., 2004; Olsen et al., 2003*a*). In comparing three separate reports on adults, elderly and children, the median PFCs values tend to be roughly similar in these age categories (Olsen et al., 2003*a*, 2004*a*, 2004*b*), and no substantial age trends were seen within adults ages 20-69 (Olsen et al., 2003*a*).

Serum Perfluorodecanoic acid (PFDeA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**< LOD**	**.300** (<LOD-.500)	**.600** (.400-1.10)	**.900** (.500-1.80)	2094
Age group							
12-19 years	03-04	*	**< LOD**	**< LOD**	**.500** (<LOD-1.00)	**.800** (.300-1.20)	640
20 years and older	03-04	*	**< LOD**	**.400** (<LOD-.500)	**.700** (.400-1.00)	**.900** (.500-1.80)	1454
Gender							
Males	03-04	*	**< LOD**	**.400** (<LOD-.500)	**.800** (.400-1.40)	**1.10** (.600-2.10)	1053
Females	03-04	*	**< LOD**	**.300** (<LOD-.400)	**.500** (.400-.800)	**.800** (.500-1.20)	1041
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**< LOD**	**.500** (.400-.500)	**.600** (.500-.800)	485
Non-Hispanic blacks	03-04	*	**< LOD**	**.400** (<LOD-.700)	**.800** (.400-1.50)	**1.00** (.500-3.10)	538
Non-Hispanic whites	03-04	*	**< LOD**	**.300** (<LOD-.500)	**.600** (.400-1.00)	**.900** (.500-1.80)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

In a study of 598 blood donors aged 20-69 (Olsen et al., 2003*a*), surprisingly little variance in across five widely-dispersed U.S. cities was seen in median PFC levels. PFOS and PFOA were shown to be highly correlated in that study and also in NHANES 2003-2004 (Calafat et al., 2007*b*), possibly due to PFOA being a by-product in POSF-related production. The median levels of various PFCs in Olsen et al. (2003*a*) were similar to those of pooled samples (1990 through 2002) of the U.S. population (Calafat et al., 2006*a*). Olsen et al (2005) also showed that PFCs serum concentrations increased from 1974 to 1989 in 58 paired samples: 25% for PFOS, 162% for PFOA, and 204% for Et-PFOSA-AcOH. Recently, Olsen et al. (2007*b*) reported reductions in PFOS and PFOA concentrations for a group of Red Cross blood donors in the United States from 2000 to 2005.

Serum levels of PFCs, particularly PFOS, appear to be higher in the U.S. than in some other countries: about two to threefold higher than in Columbia, Brazil, Poland, Belgium, Malaysia, Korea and Japan; and about eight to sixteenfold higher than in Italy and India (Kannan et al., 2004); and more than thirtyfold higher than in Peru (Calafat et al., 2006*b*). Notably, the sample sizes were small in these studies. In Japan, PFOS levels tended to vary within regions of the country ranging from U.S. median levels to about fivefold lower levels (Harada et al., 2004). PFC levels for the U.S. population, representing environmental exposures, are much lower than those reported for occupational exposure. In monitored workers employed at a POSF production facility with no biochemical or clinically observable effects, median levels of PFOS and PFOA were over 40 to 300-fold higher, respectively (Olsen et al., 2003*b*).

Finding a measurable amount of PFCs in serum does not mean that the levels of PFCs cause an adverse health effect. Biomonitoring studies of serum PFCs can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of PFCs than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum Perfluorododecanoic acid (PFDoA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2094
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	640
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1454
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1053
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	485
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	538
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.0.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum Perfluoroheptanoic acid (PFHpA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	**.400** (<LOD-.500)	2094
Age group							
12-19 years	03-04	*	< LOD	< LOD	**.400** (<LOD-.600)	**.600** (.500-.900)	640
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1454
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	**.300** (<LOD-.400)	1053
Females	03-04	*	< LOD	< LOD	< LOD	**.400** (.300-.600)	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	**.500** (<LOD-.900)	485
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	538
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	**.300** (<LOD-.500)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum Perfluorohexane sulfonic acid (PFHxS)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**1.93** (1.73-2.16)	**1.90** (1.70-2.10)	**3.30** (2.80-3.90)	**5.90** (4.80-7.20)	**8.30** (7.10-9.70)	2094
Age group							
12-19 years	03-04	**2.44** (2.05-2.90)	**2.40** (1.80-3.20)	**4.90** (4.00-6.30)	**9.50** (6.80-12.5)	**13.3** (9.90-19.6)	640
20 years and older	03-04	**1.86** (1.67-2.08)	**1.80** (1.60-2.10)	**3.00** (2.60-3.60)	**5.50** (4.50-6.70)	**7.60** (6.30-9.40)	1454
Gender							
Males	03-04	**2.17** (1.87-2.51)	**2.10** (1.80-2.40)	**3.40** (2.80-4.50)	**6.10** (4.60-8.10)	**8.50** (6.50-10.5)	1053
Females	03-04	**1.72** (1.56-1.91)	**1.60** (1.40-1.80)	**2.90** (2.50-3.50)	**5.80** (4.60-7.10)	**8.20** (6.70-10.0)	1041
Race/ethnicity							
Mexican Americans	03-04	**1.42** (1.17-1.72)	**1.50** (1.20-1.70)	**2.30** (1.90-2.90)	**4.30** (3.10-5.10)	**5.50** (4.00-8.90)	485
Non-Hispanic blacks	03-04	**1.92** (1.62-2.26)	**1.90** (1.60-2.20)	**3.50** (2.80-4.60)	**6.00** (5.00-7.10)	**8.30** (6.30-12.0)	538
Non-Hispanic whites	03-04	**2.01** (1.77-2.27)	**1.90** (1.70-2.20)	**3.30** (2.80-4.10)	**6.10** (4.70-7.80)	**8.20** (6.90-10.1)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.

Serum Perfluorononanoic acid (PFNA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.966** (.816-1.14)	**1.00** (.900-1.10)	**1.50** (1.20-1.80)	**2.30** (1.60-4.30)	**3.20** (1.80-7.70)	2094
Age group							
12-19 years	03-04	**.852** (.697-1.04)	**.800** (.700-1.00)	**1.20** (1.00-1.60)	**1.90** (1.20-3.70)	**2.80** (1.30-6.30)	640
20 years and older	03-04	**.984** (.835-1.16)	**1.00** (.900-1.10)	**1.50** (1.20-1.80)	**2.40** (1.60-4.40)	**3.40** (1.80-8.40)	1454
Gender							
Males	03-04	**1.09** (.912-1.30)	**1.10** (.900-1.20)	**1.60** (1.40-1.90)	**2.40** (1.70-5.00)	**4.00** (1.80-8.70)	1053
Females	03-04	**.861** (.721-1.03)	**.900** (.800-1.00)	**1.30** (1.00-1.70)	**2.20** (1.40-3.40)	**3.00** (1.70-6.10)	1041
Race/ethnicity							
Mexican Americans	03-04	**.689** (.586-.809)	**.700** (.600-.900)	**1.10** (.900-1.40)	**1.60** (1.30-2.00)	**2.00** (1.60-2.80)	485
Non-Hispanic blacks	03-04	**1.14** (.834-1.54)	**1.10** (.900-1.40)	**1.70** (1.20-2.90)	**3.20** (1.50-6.50)	**4.70** (2.10-9.30)	538
Non-Hispanic whites	03-04	**.963** (.826-1.12)	**.900** (.900-1.10)	**1.50** (1.20-1.70)	**2.30** (1.60-3.60)	**3.00** (1.80-6.20)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.1.

Serum Perfluorooctanoic acid (PFOA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**3.95** (3.65-4.27)	**4.10** (3.80-4.40)	**5.80** (5.30-6.40)	**7.80** (6.70-9.60)	**9.80** (7.40-14.1)	2094
Age group							
12-19 years	03-04	**3.89** (3.47-4.35)	**4.00** (3.50-4.50)	**5.40** (4.60-6.10)	**7.00** (5.60-9.20)	**8.60** (5.90-12.6)	640
20 years and older	03-04	**3.96** (3.67-4.27)	**4.10** (3.90-4.40)	**5.90** (5.40-6.50)	**7.80** (6.80-9.60)	**9.90** (7.60-14.2)	1454
Gender							
Males	03-04	**4.47** (4.07-4.91)	**4.60** (4.30-5.00)	**6.30** (5.70-7.20)	**8.40** (6.80-12.5)	**10.7** (7.40-17.5)	1053
Females	03-04	**3.50** (3.21-3.82)	**3.60** (3.30-3.90)	**5.20** (4.70-5.80)	**7.10** (6.30-8.20)	**8.60** (7.40-10.6)	1041
Race/ethnicity							
Mexican Americans	03-04	**3.11** (2.84-3.40)	**3.30** (3.10-3.70)	**4.50** (4.20-5.20)	**6.70** (5.70-7.30)	**7.60** (6.70-10.5)	485
Non-Hispanic blacks	03-04	**3.37** (2.99-3.79)	**3.70** (3.20-4.20)	**5.20** (4.40-6.30)	**7.70** (5.30-11.6)	**9.60** (6.50-13.9)	538
Non-Hispanic whites	03-04	**4.18** (3.85-4.53)	**4.30** (3.90-4.70)	**6.00** (5.50-6.70)	**7.90** (7.20-9.20)	**9.90** (7.60-13.3)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.1.

Serum Perfluorooctane sulfonic acid (PFOS)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**20.7** (19.2-22.3)	**21.2** (19.8-22.4)	**30.0** (27.5-33.0)	**41.3** (35.6-50.0)	**54.6** (44.0-66.5)	2094
Age group							
12-19 years	03-04	**19.3** (17.5-21.4)	**19.9** (17.8-22.0)	**27.1** (23.7-30.2)	**36.5** (28.6-45.6)	**42.6** (35.1-52.1)	640
20 years and older	03-04	**20.9** (19.3-22.5)	**21.4** (19.8-22.8)	**30.4** (28.1-33.0)	**42.7** (35.7-53.3)	**57.8** (45.7-69.4)	1454
Gender							
Males	03-04	**23.2** (21.1-25.6)	**23.9** (22.4-25.5)	**32.2** (28.8-35.9)	**45.3** (35.5-62.7)	**62.7** (43.8-81.8)	1053
Females	03-04	**18.4** (17.0-20.0)	**18.2** (16.9-19.8)	**27.4** (23.8-30.2)	**39.8** (34.4-42.6)	**46.6** (42.3-61.5)	1041
Race/ethnicity							
Mexican Americans	03-04	**14.7** (13.0-16.6)	**15.9** (13.4-17.9)	**21.2** (18.7-23.5)	**28.1** (24.1-35.0)	**35.5** (28.9-38.5)	485
Non-Hispanic blacks	03-04	**21.6** (19.1-24.4)	**22.1** (19.6-24.9)	**32.3** (28.1-36.2)	**43.8** (37.2-57.3)	**57.7** (43.8-78.4)	538
Non-Hispanic whites	03-04	**21.4** (19.9-23.1)	**22.0** (20.5-23.0)	**30.2** (27.7-33.3)	**41.7** (35.7-49.6)	**56.3** (44.0-70.0)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.

Serum Perfluorooctane sulfonamide (PFOSA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.300-.400)	2094
Age group							
12-19 years	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.200-.500)	640
20 years and older	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.300-.400)	1454
Gender							
Males	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.200-.500)	1053
Females	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.300-.500)	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	.200 (<LOD-.300)	485
Non-Hispanic blacks	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.200-.500)	538
Non-Hispanic whites	03-04	*	< LOD	< LOD	.300 (.200-.300)	.300 (.300-.500)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.2.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2-(N-Ethyl-perfluorooctane sulfonamido) acetic acid (Et-PFOSA-AcOH)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	2094
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	640
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1454
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	1053
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	485
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	.400 (<LOD-.500)	538
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2-(N-Methyl-perfluorooctane sulfonamido) acetic acid (Me-PFOSA-AcOH)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	.700 (<LOD-.700)	1.00 (.900-1.10)	1.30 (1.10-1.50)	2094
Age group							
12-19 years	03-04	*	< LOD	.700 (<LOD-.800)	1.10 (.900-1.30)	1.50 (1.20-1.80)	640
20 years and older	03-04	*	< LOD	.700 (<LOD-.700)	1.00 (.900-1.10)	1.20 (1.10-1.60)	1454
Gender							
Males	03-04	*	< LOD	.700 (<LOD-.700)	1.10 (.900-1.20)	1.30 (1.10-1.70)	1053
Females	03-04	*	< LOD	.600 (<LOD-.700)	1.00 (.900-1.10)	1.10 (1.00-1.80)	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	.700 (<LOD-.900)	.900 (<LOD-1.30)	485
Non-Hispanic blacks	03-04	*	< LOD	.800 (<LOD-.900)	1.10 (.900-1.40)	1.50 (1.10-1.80)	538
Non-Hispanic whites	03-04	*	< LOD	.700 (<LOD-.800)	1.00 (.900-1.10)	1.30 (1.10-1.60)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.6.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum Perfluoroundecanoic acid (PFUA)

Geometric mean and selected percentiles of serum concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	.600 (<LOD-1.30)	2094
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	.300 (<LOD-1.10)	640
20 years and older	03-04	*	< LOD	< LOD	.300 (<LOD-.600)	.600 (<LOD-1.40)	1454
Gender							
Males	03-04	*	< LOD	< LOD	.400 (<LOD-1.00)	.700 (<LOD-2.30)	1053
Females	03-04	*	< LOD	< LOD	< LOD	.400 (<LOD-.700)	1041
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	485
Non-Hispanic blacks	03-04	*	< LOD	< LOD	.600 (<LOD-1.40)	.900 (.300-2.90)	538
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	.500 (<LOD-.900)	962

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Phthalates

General Information

Phthalates are industrial chemicals that are added to plastics to impart flexibility and resilience and are often referred to as *plasticizers*. Phthalates are also used as solubilizing and stabilizing agents in other applications. There are numerous products that contain phthalates: adhesives; automotive plastics; detergents; lubricating oils; some medical devices and pharmaceuticals; plastic raincoats; solvents; vinyl tiles and flooring; and personal-care products, such as soap, shampoo, deodorants, lotions, fragrances, hair spray, and nail polish. Phthalates are often used in polyvinyl chloride type plastics, such as plastic bags, garden hoses, inflatable recreational toys, blood product storage bags, intravenous medical tubing, and toys (ATSDR, 2001, 2002). Because they are not chemically bound to the plastics to which they are added, phthalates can be released into the environment during use or disposal of the product. Various phthalate esters have been measured in specific foods, indoor and ambient air, indoor dust, water sources, and sediments (Clark et al., 2003).

People are exposed through ingestion, inhalation, and, to a lesser extent, dermal contact with products that contain phthalates. For the general population, dietary sources have been considered as the major exposure route, followed by inhaling indoor air. Infants may have relatively greater exposures from ingesting indoor dust containing some phthalates (Clark et al., 2003). Human milk can be a source of phthalate exposure for nursing infants (Calafat et al., 2004; Mortensen et al., 2005). The intravenous or parenteral exposure route can be important in patients undergoing medical procedures involving devices or materials containing phthalates. In settings where workers may be exposed to higher air phthalate concentrations than the general population, urinary metabolite and air phthalate concentrations are roughly correlated (Liss et al., 1985; Nielsen et al., 1985; Pan et al., 2006).

Phthalates are metabolized and excreted quickly and do not accumulate in the body (Anderson et al., 2001). Ingested phthalate diesters are initially hydrolyzed in the intestine to the corresponding monoesters, which are then absorbed (Albro et al., 1982; Albro and Lavenhar, 1989). Absorbed monoester metabolites are usually oxidized in the body and, in humans, excreted in urine largely as glucuronide conjugates (Albro et al., 1982; Dirven et al., 1993). The table shows the phthalate diesters, corresponding monoester metabolites, and other oxidized metabolites included in this *Report.*

Human health effects from phthalates at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Phthalates have low acute animal toxicity. In chronic rodent studies, several of the phthalates produced testicular injury, liver injury, liver cancer, and teratogenicity, but these effects either have not been demonstrated when tested in non-human primates or are yet to be studied. *In vitro* studies showed that certain phthalates can bind to estrogen receptors and may have weak estrogenic or anti-estrogenic activity (Coldham et al., 1997; Harris et al., 1997; Jobling et al., 1995), but *in vivo* studies did not support phthalates having estrogenic effects (Milligan et al., 1998; Okubo et al., 2003; Parks et al., 2000; Zacharewski et al., 1998); however, not all phthalates

Phthalates and Urinary Metabolites in this *Report*

Phthalate name (CAS number)	**Abbreviation**	**Urinary metabolite** (CAS number)	**Abbreviation**
Benzylbutyl phthalate (85-68-7)	BzBP	Mono-benzyl phthalate (2528-16-7) (some mono-n-butyl phthalate)	MBzP
Dibutyl phthalates (84-74-2)	DBP	Mono-isobutyl phthalate	MiBP
		Mono-n-butyl phthalate (131-70-4)	MnBP
Dicyclohexyl phthalate (84-61-7)	DCHP	Mono-cyclohexyl phthalate (7517-36-4)	MCHP
Diethyl phthalate (84-66-2)	DEP	Mono-ethyl phthalate (2306-33-4)	MEP
Di-2-ethylhexyl phthalate (117-81-7)	DEHP	Mono-2-ethylhexyl phthalate (4376-20-9)	MEHP
		Mono-(2-ethyl-5-hydroxyhexyl) phthalate	MEHHP
		Mono-(2-ethyl-5-oxohexyl) phthalate	MEOHP
		Mono-(2-ethyl-5-carboxypentyl) phthalate (40809-41-4)	MECPP
Di-isononyl phthalate (28553-12-0)	DiNP	Mono-isononyl phthalate	MiNP
Dimethyl phthalate (131-11-3)	DMP	Mono-methyl phthalate (4376-18-5)	MMP
Di-n-octyl phthalate (117-84-0)	DOP	Mono-(3-carboxypropyl) phthalate	MCPP
		Mono-n-octyl phthalate (5393-19-1)	MOP

and metabolites have been tested. In animals, phthalates produced anti-androgenic effects by reducing testosterone production and, at very high levels, reducing estrogen production, effects that may be mediated by inhibiting testicular and ovarian steroidogenesis. High doses of di-2-ethylhexyl phthalate (DEHP), dibutyl phthalate (DBP), and benzylbutyl phthalate (BzBP) during the fetal period produced lowered testosterone levels, testicular atrophy, and Sertoli cell abnormalities in the male animals and, at higher doses, ovarian abnormalities in the female animals (Jarfelt et al., 2005; Lovekamp-Swan and Davis, 2003; McKee et al., 2004; NTP-CERHR, 2000*a*, 2000*b*, 2000*c*, 2006). Phthalate urinary metabolite levels in men evaluated at an infertility clinic were associated with several measures of sperm function and morphology (Duty et al., 2004; Hauser et al., 2007), but similar findings were not present in young Swedish men with comparable or higher median levels of urinary metabolites (Jonsson et al., 2005).

The monoester metabolites are thought to mediate toxic effects for some of the phthalates, but there are known species-related differences in the hydrolysis of diester phthalates, efficiency of intestinal absorption, and extent of metabolite conjugation to glucuronide (Albro et al., 1982; Kessler et al., 2004; Rhodes et al., 1986). These differences may contribute to species-specific differences in toxicity (ATSDR, 2001, 2002). Also, phthalates have been shown to induce peroxisomal proliferation in rodents, which may be a pathway to the development of liver toxicity and cancers in these animals. However, peroxisomal proliferation may not be a relevant pathway in humans (Rusyn et al., 2006).

The National Toxicology Program's Center for the Evaluation of Risks to Human Reproduction (NTP-CERHR) has reviewed the developmental and reproductive effects of specific phthalates (http://cerhr.niehs.nih.gov/reports/index.html). Information about external exposure (i.e., environmental levels) and health effects is also available for some phthalates from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Urinary levels of phthalate metabolites reflect recent exposure to the parent phthalate diester. The proportions of each metabolite for a given phthalate may vary by differing routes of exposure (Liss et al., 1985; Peck and Albro, 1982). Variation occurs from person to person in the proportions or amounts of a metabolite excreted after similar doses (Anderson et al., 2001); variation also occurs in the same person during repetitive monitoring (Fromme et al., 2007; Hauser et al., 2004; Hoppin et al., 2002). Population estimates of concentrations of specific phthalate metabolites may differ by age, gender, and race/ethnicity (Silva et al., 2004).

Finding a measurable amount of one or more phthalate metabolites in urine does not mean that the levels of the metabolites or the parent phthalate cause an adverse health effect. Biomonitoring studies on levels of phthalate metabolites provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of phthalates than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Benzylbutyl Phthalate

CAS No. 85-68-7

General Information

Benzylbutyl phthalate (BzBP) is a solvent and additive used in products such as adhesives, vinyl tile, sealants, car care products, and to a lesser extent, some personal care products. BzBP can be released into the environment during its production and, because it is not bound to products in which it is incorporated, it can be released into the ambient air during use or disposal of the products. Food crops take up BzBP, and diet is the major source for general population exposure. People exposed to BzBP will excrete mono-benzyl phthalate (MBzP) and small amounts of mono-n-butyl phthalate in their urine. High dose BzBP and its monoester metabolites, including MBzP, can produce developmental and reproductive toxicity in rodents, particularly male animals (McKee et al., 2004; NTP-CERHR, 2000). IARC considers BzBP not classifiable with respect to human carcinogenicity.

Biomonitoring Information

The median levels of MBzP in NHANES subsamples from 1999-2000, 2001-2002, and 2003-2004 were generally similar those reported in U.S. residents (Blount et al., 2000), in a small sample of pregnant women in New

Urinary Mono-benzyl phthalate (MBzP)

Metabolite of Benzylbutyl phthalate (BzBP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**15.3** (13.7-17.1)	**17.0** (15.3-18.9)	**35.4** (32.6-39.7)	**67.1** (55.3-82.4)	**103** (94.6-116)	2541
	01-02	**15.1** (13.9-16.3)	**15.8** (14.8-17.4)	**38.0** (34.5-41.2)	**80.8** (71.3-88.2)	**122** (102-142)	2782
	03-04	**13.7** (12.7-14.9)	**14.3** (12.8-16.4)	**32.3** (30.1-35.0)	**66.5** (57.3-75.6)	**101** (85.3-125)	2605
Age group							
6-11 years	99-00	**39.4** (32.9-47.2)	**40.3** (33.8-48.6)	**82.0** (55.8-98.1)	**129** (98.1-214)	**214** (108-399)	328
	01-02	**33.4** (29.1-38.4)	**37.0** (26.6-43.4)	**68.5** (61.6-92.8)	**166** (116-191)	**235** (183-330)	393
	03-04	**33.9** (28.2-40.6)	**35.0** (30.1-39.8)	**63.8** (50.4-92.4)	**145** (110-213)	**255** (146-365)	342
12-19 years	99-00	**25.6** (21.9-30.0)	**28.3** (22.3-34.8)	**51.2** (43.7-58.5)	**88.5** (67.2-115)	**125** (93.7-170)	752
	01-02	**23.2** (19.9-27.2)	**24.9** (21.2-31.0)	**55.5** (47.4-62.9)	**113** (91.8-133)	**169** (134-198)	742
	03-04	**22.1** (19.4-25.1)	**24.9** (22.3-27.2)	**49.9** (39.8-64.6)	**89.8** (71.1-120)	**152** (99.9-190)	729
20 years and older	99-00	**12.4** (10.9-14.2)	**13.8** (12.1-15.6)	**29.2** (25.2-33.1)	**52.0** (43.9-62.5)	**86.3** (54.7-119)	1461
	01-02	**12.7** (11.7-13.9)	**13.9** (12.8-14.9)	**31.8** (28.5-33.5)	**65.4** (53.8-76.3)	**99.7** (82.8-121)	1647
	03-04	**11.4** (10.3-12.7)	**12.1** (10.8-13.5)	**27.0** (23.6-29.4)	**54.2** (47.1-61.5)	**79.5** (66.5-94.8)	1534
Gender							
Males	99-00	**16.2** (14.1-18.6)	**17.7** (15.2-20.0)	**35.4** (31.5-40.3)	**69.4** (59.9-87.2)	**108** (96.3-130)	1215
	01-02	**15.6** (13.6-17.9)	**16.0** (14.6-18.5)	**37.0** (33.1-43.0)	**78.4** (63.5-97.4)	**122** (88.2-183)	1371
	03-04	**14.6** (13.2-16.2)	**15.1** (13.2-17.5)	**32.3** (29.5-35.6)	**65.6** (53.6-79.6)	**101** (78.6-132)	1250
Females	99-00	**14.6** (12.7-16.6)	**16.1** (14.2-19.2)	**35.8** (30.8-41.4)	**63.7** (53.7-82.4)	**103** (84.2-116)	1326
	01-02	**14.6** (13.1-16.3)	**15.4** (13.8-17.9)	**38.1** (32.3-43.8)	**81.4** (68.3-91.6)	**122** (102-143)	1411
	03-04	**13.0** (11.8-14.2)	**13.3** (12.1-15.6)	**33.3** (29.5-36.2)	**67.1** (58.8-72.4)	**101** (84.4-120)	1355
Race/ethnicity							
Mexican Americans	99-00	**13.9** (12.1-16.1)	**15.7** (13.4-16.9)	**33.0** (27.5-36.1)	**67.5** (55.5-84.0)	**98.8** (80.6-150)	814
	01-02	**13.2** (10.8-16.2)	**14.8** (10.8-18.5)	**29.5** (26.2-38.1)	**70.4** (53.0-85.4)	**94.7** (70.3-161)	677
	03-04	**14.9** (13.2-16.7)	**15.5** (13.5-18.3)	**32.4** (27.7-35.4)	**71.4** (48.6-92.3)	**99.8** (86.5-145)	652
Non-Hispanic blacks	99-00	**23.0** (20.7-25.5)	**23.1** (20.5-25.6)	**49.3** (44.0-55.6)	**94.7** (80.0-130)	**138** (106-241)	603
	01-02	**23.8** (21.0-26.9)	**24.2** (19.9-28.0)	**50.6** (41.5-62.9)	**101** (86.4-127)	**143** (127-179)	703
	03-04	**18.9** (16.3-21.8)	**20.0** (15.4-24.6)	**43.8** (38.9-49.0)	**80.9** (70.0-106)	**120** (99.7-172)	699
Non-Hispanic whites	99-00	**14.3** (12.7-16.1)	**16.1** (14.3-18.6)	**34.0** (30.6-38.4)	**58.7** (51.3-74.1)	**103** (74.1-116)	912
	01-02	**14.0** (12.7-15.4)	**14.6** (13.4-15.6)	**35.6** (32.2-39.5)	**76.6** (66.1-90.3)	**122** (93.2-155)	1216
	03-04	**12.9** (11.5-14.3)	**13.2** (11.7-16.0)	**30.5** (27.8-35.1)	**63.8** (53.6-72.4)	**91.5** (76.3-122)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.8, 0.3, and 0.1, respectively.

York City (Adibi et al., 2003), in men attending a Boston infertility clinic (Duty et al., 2004; Hauser et al., 2007), in young Swedish men (Jonsson et al., 2005), and in a small sample of German residents (Koch et al., 2003). In an annual sample of German university students, median urine levels of MBzP were about one-half the median levels in NHANES subsamples from 1999-2002 (Wittassek et al., 2007). A small study of African-American women in Washington, DC reported median urinary MBzP levels that were about twice the levels of adults and females reported in NHANES 1999-2002 (CDC, 2005; Hoppin et al., 2002). Limited studies in children younger than 2 years old have found median and geometric mean urine MBzP that were similar to children aged 6-11 years in the NHANES subsamples (Brock et al., 2002; Weuve et al., 2006). In NHANES 1999-2000, the adjusted geometric mean levels of urinary MBzP were significantly higher in several subgroups: children compared to adolescents and adults; adolescents compared with adults; and females compared to males (Silva et al., 2004).

Finding a measurable amount of MBzP in the urine does not mean that the levels of MBzP or the parent compound cause an adverse health effect. Biomonitoring studies on levels of urinary MBzP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of BzBP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-benzyl phthalate (MBzP) (creatinine corrected)

Metabolite of Benzylbutyl phthalate (BzBP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**14.0** (13.0-15.0)	**13.3** (12.8-14.3)	**25.1** (23.4-27.2)	**50.1** (41.5-58.8)	**77.4** (69.6-86.3)	2541
	01-02	**14.1** (13.2-15.1)	**13.5** (12.7-14.4)	**26.6** (24.7-29.1)	**54.8** (49.1-58.5)	**90.4** (74.4-102)	2782
	03-04	**12.9** (12.2-13.7)	**12.6** (11.2-13.6)	**24.6** (22.2-26.4)	**46.0** (41.0-51.5)	**70.0** (62.4-79.9)	2605
Age group							
6-11 years	99-00	**40.0** (33.6-47.6)	**38.6** (30.2-51.3)	**73.5** (56.6-99.2)	**104** (89.4-142)	**142** (99.8-173)	328
	01-02	**38.1** (34.4-42.1)	**37.4** (33.8-42.2)	**67.9** (55.8-80.4)	**134** (116-176)	**195** (121-305)	393
	03-04	**35.8** (30.5-42.1)	**32.2** (27.9-40.5)	**60.8** (50.1-79.4)	**136** (85.5-213)	**229** (99.7-397)	342
12-19 years	99-00	**17.3** (15.4-19.4)	**17.1** (14.6-20.3)	**28.3** (24.3-34.8)	**49.7** (38.8-69.3)	**70.0** (49.6-81.9)	752
	01-02	**17.9** (15.7-20.5)	**18.1** (15.7-20.8)	**33.9** (29.3-38.6)	**67.7** (55.8-85.9)	**100** (80.7-123)	742
	03-04	**16.6** (15.4-17.8)	**16.9** (15.4-18.2)	**30.1** (25.1-35.5)	**52.2** (40.7-61.8)	**77.7** (54.9-115)	729
20 years and older	99-00	**11.8** (10.7-12.9)	**12.1** (11.1-12.9)	**20.1** (18.4-23.3)	**34.6** (30.6-40.9)	**57.2** (41.3-73.9)	1461
	01-02	**12.0** (11.2-12.9)	**11.8** (11.1-12.5)	**21.6** (19.9-23.7)	**42.3** (35.8-48.3)	**64.9** (54.2-78.3)	1647
	03-04	**11.0** (10.3-11.7)	**10.5** (9.69-11.6)	**19.7** (18.2-21.4)	**36.6** (34.8-39.1)	**55.8** (46.9-62.4)	1534
Gender							
Males	99-00	**12.7** (11.8-13.6)	**12.4** (11.6-13.0)	**23.7** (21.5-26.1)	**44.5** (35.5-57.0)	**73.5** (48.5-99.8)	1215
	01-02	**12.7** (11.4-14.2)	**11.9** (10.9-13.2)	**24.1** (21.0-26.4)	**49.1** (43.7-56.1)	**80.3** (60.9-104)	1371
	03-04	**11.5** (10.6-12.4)	**11.1** (9.73-12.5)	**21.1** (19.5-23.6)	**39.4** (34.2-49.7)	**62.9** (51.9-83.1)	1250
Females	99-00	**15.3** (13.8-16.8)	**14.7** (13.3-16.0)	**25.9** (24.1-29.3)	**56.4** (46.8-60.6)	**80.4** (60.2-117)	1326
	01-02	**15.6** (14.2-17.3)	**15.1** (13.9-16.5)	**29.4** (25.8-34.1)	**58.5** (49.9-69.4)	**95.8** (69.4-116)	1411
	03-04	**14.4** (13.4-15.6)	**13.9** (12.8-15.1)	**27.9** (24.7-31.4)	**51.9** (43.4-60.3)	**73.4** (63.7-90.2)	1355
Race/ethnicity							
Mexican Americans	99-00	**12.6** (11.4-14.0)	**11.9** (10.9-13.2)	**24.1** (21.5-26.5)	**46.5** (42.0-53.8)	**68.2** (56.4-93.8)	814
	01-02	**12.4** (10.7-14.4)	**11.9** (9.95-14.9)	**23.7** (19.5-29.0)	**46.6** (36.5-61.6)	**71.6** (51.1-120)	677
	03-04	**13.4** (11.7-15.4)	**12.5** (11.5-13.4)	**24.1** (21.0-27.8)	**53.0** (38.3-64.8)	**77.8** (57.1-125)	652
Non-Hispanic blacks	99-00	**14.8** (13.5-16.3)	**13.7** (12.2-15.2)	**26.9** (22.5-31.8)	**56.3** (39.5-76.0)	**86.8** (64.4-99.8)	603
	01-02	**16.7** (14.7-19.0)	**15.7** (13.7-19.3)	**33.4** (26.5-38.0)	**60.1** (53.7-69.4)	**108** (75.6-116)	703
	03-04	**13.4** (11.8-15.3)	**13.6** (11.6-15.6)	**24.1** (21.9-28.7)	**50.0** (41.2-57.8)	**74.7** (59.0-90.5)	699
Non-Hispanic whites	99-00	**14.0** (12.7-15.3)	**13.4** (12.9-14.8)	**25.3** (23.1-27.4)	**53.3** (38.8-64.8)	**78.0** (67.4-90.3)	912
	01-02	**13.8** (12.8-14.9)	**13.0** (12.1-14.3)	**25.7** (23.8-27.9)	**53.1** (46.5-58.5)	**89.2** (69.0-109)	1216
	03-04	**12.7** (11.8-13.7)	**12.5** (10.8-13.8)	**24.4** (21.6-26.7)	**41.9** (39.0-48.8)	**65.6** (57.5-79.5)	1088

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Di-n-butyl Phthalate
CAS No. 84-74-2

Di-isobutyl Phthalate
CAS No. 84-69-5

General Information

Dibutyl phthalates (both di-n-butyl and di-isobutyl phthalates, referred to as DBP) are industrial solvents or additives used in many personal care products such as nail polish and cosmetics, and also in some printing inks, pharmaceutical coatings, and insecticides. People exposed to dibutyl phthalates will excrete mono-n-butyl phthalate (MnBP) and mono-isobutyl phthalate (MiBP) in their urine. When total DBP metabolites have been measured, they have been referred to as monobutyl phthalate (MBP). Small amounts of mono-3-carboxypropyl phthalate are also produced from di-n-butyl phthalate. In addition, exposure to benzylbutyl phthalate (BzBP) will also result in small amounts of mono-n-butyl phthalate appearing in the urine. Following oral administration of DBP to humans, about 65% to 80% of a dose is eliminated in urine within 24 hours, mostly as MnBP (Anderson et al., 2001). DBP can produce reproductive toxicity in male rodents (McKee et al., 2004; NTP-CERHR, 2000). OSHA has established a workplace air standard for external exposure to DBP; NIOSH and ACGIH have established guidelines for workplace air exposure to di-n-butyl phthalate. Neither IARC nor NTP has evaluated dibutyl phthalates with respect to human carcinogenicity.

Biomonitoring Information

Median concentrations reported in the NHANES 1999-2000, 2001-2002 and 2003-2004 subsamples were similar to MBP levels reported in U.S. residents (Blount et al., 2000; CDC, 2005), in men attending a Boston infertility clinic (Duty et al., 2004; Hauser et al., 2007), in a small sample of pregnant women in New York City (Adibi et al., 2003), and in a small sample of Japanese adults (Itoh et al., 2005). Median MBP levels in two European studies were about two to six times higher than median levels in this *Report* (Jonsson et al., 2005; Koch et al., 2003). Studies of children found age-related differences in urine MBP levels. Compared with the median for 6 to 11 year olds in NHANES 1999-2004 (CDC, 2005), the median

Urinary Mono-isobutyl phthalate (MiBP)
Metabolite of Di-isobutyl phthalate (DBP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2.71** (2.49-2.94)	**2.70** (2.40-3.00)	**5.70** (5.30-6.10)	**12.0** (11.4-12.7)	**17.9** (16.3-19.8)	2782
	03-04	**3.80** (3.40-4.25)	**4.20** (3.70-4.80)	**8.40** (7.40-9.50)	**15.0** (13.1-17.3)	**21.3** (18.6-26.0)	2605
Age group							
6-11 years	01-02	**4.22** (3.28-5.43)	**4.40** (3.20-6.20)	**10.7** (7.30-13.4)	**18.6** (14.2-22.0)	**23.4** (20.4-27.8)	393
	03-04	**6.56** (5.24-8.22)	**7.00** (5.10-9.10)	**12.8** (9.40-17.7)	**24.3** (19.6-34.5)	**40.6** (29.3-48.5)	342
12-19 years	01-02	**3.48** (2.90-4.17)	**3.80** (2.90-4.40)	**7.40** (6.00-9.00)	**14.5** (11.7-18.6)	**22.3** (16.2-33.4)	742
	03-04	**4.55** (3.73-5.55)	**5.60** (4.50-6.30)	**10.1** (8.00-11.4)	**17.1** (13.3-20.9)	**22.7** (18.5-29.1)	729
20 years and older	01-02	**2.46** (2.30-2.63)	**2.40** (2.20-2.70)	**5.10** (4.80-5.50)	**10.6** (9.40-12.0)	**16.3** (13.6-18.5)	1647
	03-04	**3.46** (3.11-3.84)	**3.90** (3.40-4.30)	**7.50** (6.70-8.50)	**13.3** (11.5-16.5)	**19.9** (16.0-25.0)	1534
Gender							
Males	01-02	**2.73** (2.50-2.97)	**2.80** (2.40-3.20)	**5.60** (5.00-6.10)	**11.6** (10.1-12.6)	**16.6** (13.6-20.1)	1371
	03-04	**4.07** (3.56-4.66)	**4.30** (3.80-5.10)	**9.20** (7.50-10.2)	**16.0** (13.3-18.5)	**22.7** (17.3-30.3)	1250
Females	01-02	**2.68** (2.44-2.96)	**2.60** (2.30-3.00)	**5.80** (5.30-6.50)	**12.6** (11.0-14.7)	**18.7** (16.3-24.0)	1411
	03-04	**3.56** (3.19-3.97)	**4.10** (3.50-4.50)	**8.00** (7.10-9.10)	**14.2** (12.5-16.6)	**20.5** (17.9-23.0)	1355
Race/ethnicity							
Mexican Americans	01-02	**3.26** (2.72-3.91)	**3.40** (2.70-4.30)	**7.20** (6.20-9.30)	**12.2** (11.2-14.7)	**18.4** (14.1-25.6)	677
	03-04	**4.81** (3.85-6.02)	**5.10** (4.00-6.70)	**10.2** (8.20-12.6)	**18.3** (13.5-24.5)	**26.0** (19.0-38.5)	652
Non-Hispanic blacks	01-02	**4.90** (4.46-5.37)	**5.30** (4.60-6.00)	**10.7** (9.20-12.0)	**18.3** (16.1-20.1)	**25.5** (20.7-31.3)	703
	03-04	**6.67** (5.97-7.46)	**6.90** (6.30-7.50)	**12.6** (10.9-14.7)	**25.7** (17.7-31.0)	**33.5** (27.3-43.9)	699
Non-Hispanic whites	01-02	**2.33** (2.10-2.59)	**2.30** (1.90-2.60)	**4.90** (4.40-5.30)	**9.60** (8.30-11.6)	**15.6** (13.0-18.6)	1216
	03-04	**3.17** (2.82-3.56)	**3.50** (3.00-4.00)	**6.80** (5.90-7.90)	**12.5** (10.6-14.5)	**17.6** (14.7-20.8)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 1.0 and 0.3.

for neonates was lower (by about half) and the median for toddlers was higher (by about sixfold) (Brock et al., 2002; Weuve et al., 2006). In an analysis of NHANES 1999-2000, the adjusted geometric mean levels of urinary MBP were significantly higher in children aged 6 to 11 years than in either adolescents or adults (Silva et al., 2004). Differences in urinary MBP population estimates by gender have also been shown (Silva et al., 2004). An analysis of NHANES 2001-2002 showed similar age- and gender- related differences in the adjusted geometric mean levels of urinary MiBP and MnBP (CDC, 2005).

Studies measuring urinary MnBP have reported variable median values compared to the NHANES 2001-2002 and 2003-2004 subsamples, ranging from more than one-tenth the NHANES median (Itoh et al., 2005), to about two to fourfold higher (Fromme et al., 2007). Between 1998 and 2003, samples from German university students had consistently higher median urine levels of MnBP and MiBP, up to four and 13 fold, respectively, than adults in NHANES subsamples during the same time period. Over this time, the students' median values for MiBP levels remained relatively unchanged, while MnBP declined (Wittassek et al., 2007).

Finding a measurable amount of MnBP or MiBP in urine does not mean that these levels or the parent compound cause an adverse health effect. Biomonitoring studies on levels of MnBP and MiBP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of dibutyl phthalates than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-isobutyl phthalate (MiBP) (creatinine corrected)

Metabolite of Di-isobutyl phthalate (DBP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2.54** (2.36-2.73)	**2.46** (2.26-2.68)	**4.54** (4.20-4.86)	**8.02** (7.78-8.66)	**12.0** (10.8-13.5)	2782
	03-04	**3.57** (3.18-4.00)	**3.57** (3.15-4.08)	**6.21** (5.36-7.17)	**10.9** (9.47-12.7)	**15.4** (12.8-18.6)	2605
Age group							
6-11 years	01-02	**4.81** (3.89-5.94)	**5.18** (4.13-6.32)	**9.20** (7.03-11.7)	**15.2** (11.1-24.3)	**24.3** (13.9-40.3)	393
	03-04	**6.94** (5.79-8.31)	**7.03** (5.29-8.95)	**11.8** (9.56-15.1)	**18.6** (15.1-25.1)	**28.7** (21.8-36.9)	342
12-19 years	01-02	**2.68** (2.29-3.15)	**2.83** (2.39-3.33)	**4.79** (4.04-5.51)	**7.62** (6.18-10.2)	**12.8** (8.76-15.6)	742
	03-04	**3.41** (2.86-4.05)	**3.69** (2.99-4.31)	**5.75** (4.69-7.04)	**9.32** (7.17-12.0)	**13.5** (9.52-20.1)	729
20 years and older	01-02	**2.33** (2.20-2.46)	**2.26** (2.08-2.43)	**3.89** (3.65-4.25)	**7.31** (7.00-7.78)	**10.6** (9.46-11.3)	1647
	03-04	**3.32** (3.00-3.68)	**3.33** (3.00-3.81)	**5.59** (4.93-6.51)	**9.84** (8.65-11.2)	**13.5** (11.4-16.0)	1534
Gender							
Males	01-02	**2.22** (2.09-2.35)	**2.18** (1.97-2.37)	**3.76** (3.58-4.11)	**7.38** (6.64-7.95)	**11.1** (10.1-12.5)	1371
	03-04	**3.20** (2.80-3.66)	**3.19** (2.74-3.56)	**5.84** (4.79-6.56)	**10.0** (8.27-12.2)	**13.9** (11.5-19.1)	1250
Females	01-02	**2.88** (2.61-3.18)	**2.85** (2.52-3.18)	**5.14** (4.67-5.89)	**8.66** (8.02-10.1)	**13.7** (11.1-15.0)	1411
	03-04	**3.96** (3.56-4.42)	**4.00** (3.57-4.45)	**6.73** (5.64-7.80)	**11.6** (10.2-13.0)	**15.7** (13.0-18.7)	1355
Race/ethnicity							
Mexican Americans	01-02	**3.07** (2.58-3.66)	**2.98** (2.53-3.82)	**5.82** (4.91-6.99)	**10.6** (8.28-13.3)	**16.0** (12.6-19.4)	677
	03-04	**4.34** (3.47-5.43)	**4.47** (3.53-5.24)	**7.75** (6.33-9.69)	**13.1** (11.9-16.8)	**23.3** (17.9-26.1)	652
Non-Hispanic blacks	01-02	**3.44** (3.20-3.69)	**3.52** (2.95-3.81)	**6.11** (5.03-7.04)	**10.6** (8.94-12.4)	**15.6** (12.6-19.7)	703
	03-04	**4.74** (4.07-5.51)	**4.65** (4.10-5.30)	**7.81** (6.38-10.0)	**15.2** (10.8-18.4)	**19.9** (15.7-28.7)	699
Non-Hispanic whites	01-02	**2.31** (2.11-2.52)	**2.20** (2.01-2.43)	**3.80** (3.53-4.39)	**7.30** (6.72-7.78)	**10.7** (9.62-12.6)	1216
	03-04	**3.13** (2.76-3.54)	**3.17** (2.76-3.72)	**5.28** (4.55-6.21)	**8.92** (7.64-10.3)	**11.8** (10.2-15.1)	1088

Urinary Mono-n-butyl phthalate (MnBP)

Metabolite of Dibutyl phthalate (DBP) and Benzylbutyl phthalate (BzBP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00*	**24.6** (22.1-27.4)	**26.0** (23.6-29.2)	**51.6** (44.5-60.3)	**98.6** (90.2-114)	**150** (121-169)	2541
	01-02	**18.9** (17.4-20.6)	**20.4** (19.2-21.8)	**40.4** (36.5-44.2)	**73.6** (65.3-85.6)	**108** (94.1-122)	2782
	03-04	**21.1** (19.8-22.5)	**23.2** (21.2-24.8)	**42.7** (38.5-47.2)	**80.7** (70.2-93.9)	**122** (104-137)	2605
Age group							
6-11 years	99-00*	**41.4** (35.6-48.0)	**40.0** (36.2-49.2)	**75.5** (59.1-92.8)	**124** (98.4-159)	**166** (127-279)	328
	01-02	**31.1** (26.6-36.5)	**32.4** (25.6-37.1)	**62.1** (51.3-76.9)	**107** (84.3-136)	**159** (110-290)	393
	03-04	**36.3** (30.7-42.9)	**36.7** (28.5-47.5)	**71.3** (56.9-87.2)	**137** (107-162)	**191** (150-243)	342
12-19 years	99-00*	**36.0** (30.8-42.1)	**36.3** (30.6-44.9)	**68.6** (55.9-79.7)	**119** (90.2-159)	**165** (121-227)	752
	01-02	**25.1** (21.6-29.2)	**26.7** (22.0-32.7)	**52.6** (48.4-60.4)	**92.4** (72.7-121)	**148** (106-185)	742
	03-04	**26.7** (24.1-29.5)	**28.2** (25.2-33.1)	**52.0** (45.3-60.9)	**97.5** (74.7-116)	**134** (110-158)	729
20 years and older	99-00*	**21.6** (19.0-24.5)	**23.1** (19.7-26.1)	**46.3** (36.9-53.6)	**95.0** (78.7-111)	**143** (117-161)	1461
	01-02	**17.0** (15.4-18.8)	**19.1** (17.1-20.4)	**35.1** (31.6-40.2)	**64.8** (57.3-79.7)	**95.4** (84.6-113)	1647
	03-04	**19.0** (17.7-20.5)	**20.7** (18.9-22.9)	**38.4** (35.7-42.7)	**74.7** (64.1-82.6)	**108** (90.7-127)	1534
Gender							
Males	99-00*	**22.0** (20.1-24.1)	**23.2** (20.4-26.3)	**43.1** (36.6-49.5)	**84.4** (71.3-96.2)	**116** (97.8-132)	1215
	01-02	**17.7** (16.0-19.6)	**19.3** (17.3-21.0)	**34.5** (30.3-40.6)	**62.1** (54.1-75.5)	**95.2** (75.5-117)	1371
	03-04	**20.0** (18.1-22.0)	**21.1** (19.0-24.0)	**39.4** (35.5-43.4)	**65.5** (59.0-73.0)	**95.9** (79.8-111)	1250
Females	99-00*	**27.3** (23.6-31.5)	**30.0** (25.9-33.3)	**59.7** (51.6-69.6)	**120** (98.3-145)	**167** (143-223)	1326
	01-02	**20.2** (18.2-22.4)	**21.7** (19.7-24.3)	**46.7** (43.1-51.1)	**85.0** (72.7-92.5)	**121** (106-136)	1411
	03-04	**22.2** (21.2-23.3)	**24.4** (23.4-25.8)	**47.3** (42.7-53.0)	**95.9** (79.9-114)	**137** (122-156)	1355
Race/ethnicity							
Mexican Americans	99-00*	**23.4** (21.8-25.1)	**26.3** (23.9-28.1)	**48.1** (41.2-56.7)	**92.2** (78.9-101)	**117** (104-131)	814
	01-02	**20.1** (16.6-24.5)	**23.1** (18.0-26.5)	**42.1** (34.0-51.5)	**77.1** (62.9-92.5)	**112** (84.6-143)	677
	03-04	**24.1** (19.8-29.5)	**26.9** (20.2-32.0)	**47.4** (38.0-58.5)	**85.6** (61.7-117)	**127** (99.8-165)	652
Non-Hispanic blacks	99-00*	**37.0** (31.9-42.9)	**38.7** (33.4-44.5)	**78.2** (58.7-91.8)	**118** (108-143)	**167** (143-197)	603
	01-02	**29.6** (26.6-33.1)	**31.5** (28.7-34.1)	**58.3** (51.2-63.4)	**93.2** (79.5-121)	**138** (110-184)	703
	03-04	**30.1** (28.4-31.9)	**31.5** (29.7-34.1)	**64.1** (58.3-67.1)	**106** (94.8-119)	**144** (115-168)	699
Non-Hispanic whites	99-00*	**21.8** (19.3-24.6)	**23.2** (19.5-27.5)	**46.3** (37.5-53.3)	**90.2** (74.7-106)	**142** (111-161)	912
	01-02	**17.6** (16.0-19.3)	**19.2** (17.0-21.0)	**36.6** (32.4-42.6)	**69.2** (59.2-87.6)	**107** (89.8-123)	1216
	03-04	**18.9** (17.6-20.3)	**20.7** (18.9-22.8)	**38.4** (35.5-42.7)	**71.3** (60.1-80.0)	**101** (90.7-124)	1088

Limits of detection (LOD, see Data Analysis section) for survey years 99-00, 01-02, and 03-04 are 0.9, 1.1, and 0.4, respectively.

*In the 1999-2000 survey period, concentrations of mono-isobutyl phthalate and mono-n-butyl phthalate were measured together and expressed as a combined value, referred to as monobutyl phthalate (MBP).

Urinary Mono-n-butyl phthalate (MnBP) (creatinine corrected)

Metabolite of Dibutyl phthalate (DBP) and Benzylbutyl phthalate (BzBP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00*	**22.4** (20.6-24.4)	**21.9** (19.8-24.3)	**38.9** (35.0-41.8)	**68.3** (60.3-78.3)	**97.7** (81.4-131)	2541
	01-02	**17.8** (16.7-19.0)	**17.4** (16.3-18.4)	**30.3** (28.1-32.3)	**52.4** (47.4-61.0)	**81.3** (71.0-92.5)	2782
	03-04	**19.8** (18.5-21.2)	**19.3** (17.7-20.8)	**33.9** (30.9-38.5)	**59.0** (52.9-68.1)	**91.6** (74.1-115)	2605
Age group							
6-11 years	99-00*	**41.9** (37.4-47.1)	**39.1** (34.3-49.0)	**65.9** (56.7-80.0)	**108** (71.2-179)	**159** (102-263)	328
	01-02	**35.4** (31.7-39.6)	**35.1** (29.3-38.9)	**55.4** (50.1-62.3)	**84.0** (69.0-113)	**147** (93.8-235)	393
	03-04	**38.4** (33.8-43.6)	**39.0** (34.7-42.6)	**59.3** (52.9-68.1)	**104** (83.6-119)	**137** (108-198)	342
12-19 years	99-00*	**24.3** (21.2-27.8)	**23.7** (20.6-27.4)	**37.6** (31.6-43.8)	**63.3** (52.4-76.4)	**88.1** (61.5-142)	752
	01-02	**19.4** (17.3-21.7)	**20.3** (17.5-22.3)	**34.9** (30.5-37.9)	**53.4** (45.2-73.9)	**89.7** (60.3-106)	742
	03-04	**20.0** (18.7-21.3)	**19.8** (18.2-21.7)	**30.7** (27.9-34.8)	**52.7** (43.4-65.4)	**74.4** (56.0-90.9)	729
20 years and older	99-00*	**20.4** (18.6-22.4)	**19.5** (18.1-21.4)	**34.9** (30.3-40.0)	**62.4** (53.4-72.1)	**91.0** (70.4-135)	1461
	01-02	**16.1** (15.0-17.3)	**15.5** (14.2-16.5)	**26.3** (24.2-28.6)	**44.2** (38.7-51.1)	**71.6** (61.2-85.6)	1647
	03-04	**18.3** (17.0-19.6)	**17.7** (16.6-19.2)	**31.0** (27.4-34.0)	**53.3** (46.5-64.2)	**83.8** (65.3-114)	1534
Gender							
Males	99-00*	**17.3** (16.1-18.6)	**17.0** (15.5-18.8)	**28.6** (25.8-32.1)	**49.3** (42.6-53.5)	**64.7** (57.3-71.5)	1215
	01-02	**14.4** (13.5-15.4)	**13.7** (12.9-14.9)	**22.9** (20.8-24.6)	**39.9** (35.6-44.0)	**60.0** (50.5-76.2)	1371
	03-04	**15.7** (14.5-16.9)	**14.8** (13.6-16.0)	**25.4** (23.6-28.1)	**41.4** (37.0-47.5)	**59.4** (50.3-81.5)	1250
Females	99-00*	**28.6** (25.3-32.3)	**28.8** (25.5-30.5)	**50.6** (41.9-56.3)	**84.3** (69.2-106)	**134** (93.6-155)	1326
	01-02	**21.7** (19.6-23.9)	**21.6** (19.7-23.6)	**35.8** (33.0-38.7)	**64.9** (58.9-70.2)	**91.5** (81.4-103)	1411
	03-04	**24.8** (22.9-26.8)	**24.1** (21.6-26.8)	**42.9** (39.2-48.9)	**74.9** (64.2-86.6)	**117** (83.6-139)	1355
Race/ethnicity							
Mexican Americans	99-00*	**21.2** (19.3-23.3)	**20.0** (18.2-22.9)	**40.1** (32.6-44.3)	**63.6** (57.5-70.1)	**82.9** (73.9-100)	814
	01-02	**19.0** (16.2-22.2)	**19.2** (16.3-21.9)	**33.7** (28.3-39.6)	**61.0** (43.9-84.0)	**86.7** (60.6-128)	677
	03-04	**21.8** (17.7-26.8)	**20.4** (17.4-24.0)	**37.6** (29.6-50.1)	**75.3** (55.6-92.0)	**96.3** (76.4-164)	652
Non-Hispanic blacks	99-00*	**23.9** (21.3-26.8)	**25.0** (20.7-28.1)	**42.2** (35.9-49.6)	**70.0** (61.1-83.9)	**96.2** (83.9-105)	603
	01-02	**20.8** (18.8-23.1)	**20.2** (19.2-22.8)	**34.5** (30.9-36.8)	**62.8** (50.6-74.6)	**85.6** (72.1-99.0)	703
	03-04	**21.4** (19.5-23.4)	**22.0** (19.6-24.8)	**35.4** (31.6-42.7)	**65.7** (54.0-75.3)	**94.0** (71.1-128)	699
Non-Hispanic whites	99-00*	**21.3** (19.1-23.8)	**20.5** (18.6-23.2)	**36.4** (31.5-41.0)	**67.1** (56.7-78.4)	**97.7** (73.5-142)	912
	01-02	**17.4** (16.2-18.6)	**16.5** (15.3-17.8)	**29.0** (26.6-32.2)	**51.1** (46.0-60.0)	**81.4** (68.1-99.0)	1216
	03-04	**18.6** (17.3-20.1)	**17.9** (16.7-19.8)	**31.6** (27.7-37.8)	**53.3** (48.2-61.5)	**81.5** (64.2-108)	1088

*In the 1999-2000 survey period, concentrations of mono-isobutyl phthalate and mono-n-butyl phthalate were measured together and expressed as a combined value.

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Dicyclohexyl Phthalate

CAS No. 84-61-7

General Information

Dicyclohexyl phthalate (DCHP) is used to stabilize some rubbers, resins, and polymers, including nitrocellulose, polyvinyl acetate, and polyvinyl chloride. People exposed to DCHP will excrete mono-cyclohexyl phthalate (MCHP) in their urine. Neither IARC nor NTP has evaluated DCHP with respect to human carcinogenicity.

Biomonitoring Information

Urinary levels of MCHP are infrequently measured and the limited population-based surveys available to date have reported most levels below the limit of detection. In this *Report*, only levels at or above the 90th percentile could be characterized.

Finding a measurable amount of MCHP in urine does not mean that the levels of MCHP or the parent compound cause an adverse health effect. Biomonitoring studies on levels of urinary MCHP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DHCP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-cyclohexyl phthalate (MCHP)

Metabolite of Dicyclohexyl phthalate (DCHP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	1.10 (<LOD-1.70)	2541
	01-02	*	< LOD	< LOD	.400 (.300-.500)	.500 (.400-.600)	2782
	03-04	*	< LOD	< LOD	< LOD	.300 (.200-.400)	2605
Age group							
6-11 years	99-00	*	< LOD	< LOD	1.00 (<LOD-1.10)	1.70 (1.00-3.80)	328
	01-02	*	< LOD	< LOD	.400 (.300-.500)	.600 (.500-.700)	393
	03-04	*	< LOD	< LOD	.300 (<LOD-.400)	.500 (.300-.500)	342
12-19 years	99-00	*	< LOD	< LOD	1.00 (<LOD-1.50)	1.70 (1.00-2.50)	752
	01-02	*	< LOD	< LOD	.400 (.300-.500)	.500 (.400-.600)	742
	03-04	*	< LOD	< LOD	.200 (<LOD-.300)	.400 (.300-.600)	729
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1461
	01-02	*	< LOD	< LOD	.400 (<LOD-.500)	.500 (.400-.600)	1647
	03-04	*	< LOD	< LOD	< LOD	.300 (.200-.300)	1534
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	1.10 (<LOD-2.00)	1215
	01-02	*	< LOD	< LOD	.400 (.300-.500)	.500 (.400-.600)	1371
	03-04	*	< LOD	< LOD	< LOD	.300 (.300-.400)	1250
Females	99-00	*	< LOD	< LOD	< LOD	1.10 (<LOD-1.90)	1326
	01-02	*	< LOD	< LOD	.400 (<LOD-.400)	.500 (.400-.500)	1411
	03-04	*	< LOD	< LOD	< LOD	.300 (.200-.500)	1355
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	814
	01-02	*	< LOD	< LOD	.400 (<LOD-.500)	.500 (.300-.700)	677
	03-04	*	< LOD	< LOD	< LOD	.300 (.200-.500)	652
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	1.10 (.900-1.20)	603
	01-02	*	< LOD	< LOD	.400 (.300-.500)	.500 (.400-.700)	703
	03-04	*	< LOD	< LOD	.300 (.200-.300)	.400 (.300-.500)	699
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	1.00 (<LOD-1.70)	912
	01-02	*	< LOD	< LOD	.400 (<LOD-.400)	.500 (.400-.600)	1216
	03-04	*	< LOD	< LOD	< LOD	.300 (.200-.400)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.9, 0.3, and 0.2, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Mono-cyclohexyl phthalate (MCHP) (creatinine corrected)

Metabolite of Dicyclohexyl phthalate (DCHP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	**3.00** (<LOD-3.33)	2541
	01-02	*	< LOD	< LOD	**.610** (.530-.690)	**.910** (.770-1.00)	2782
	03-04	*	< LOD	< LOD	< LOD	**.450** (.400-.500)	2605
Age group							
6-11 years	99-00	*	< LOD	< LOD	**1.54** (<LOD-2.34)	**2.82** (1.54-6.44)	328
	01-02	*	< LOD	< LOD	**.690** (.510-.740)	**.940** (.690-1.17)	393
	03-04	*	< LOD	< LOD	**.370** (<LOD-.530)	**.530** (.350-.830)	342
12-19 years	99-00	*	< LOD	< LOD	**1.22** (<LOD-1.54)	**1.67** (1.36-1.82)	752
	01-02	*	< LOD	< LOD	**.470** (.380-.660)	**.770** (.530-1.18)	742
	03-04	*	< LOD	< LOD	**.220** (<LOD-.270)	**.380** (.240-.620)	729
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1461
	01-02	*	< LOD	< LOD	**.630** (<LOD-.690)	**.910** (.770-1.05)	1647
	03-04	*	< LOD	< LOD	< LOD	**.450** (.400-.500)	1534
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**2.14** (<LOD-3.16)	1215
	01-02	*	< LOD	< LOD	**.510** (.420-.660)	**.880** (.670-1.06)	1371
	03-04	*	< LOD	< LOD	< LOD	**.330** (.290-.500)	1250
Females	99-00	*	< LOD	< LOD	< LOD	**3.33** (<LOD-3.53)	1326
	01-02	*	< LOD	< LOD	**.670** (<LOD-.770)	**.910** (.800-1.10)	1411
	03-04	*	< LOD	< LOD	< LOD	**.500** (.420-.590)	1355
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	814
	01-02	*	< LOD	< LOD	**.590** (<LOD-.690)	**.950** (.790-1.11)	677
	03-04	*	< LOD	< LOD	< LOD	**.390** (.310-.560)	652
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**1.43** (1.12-1.74)	603
	01-02	*	< LOD	< LOD	**.410** (.360-.490)	**.590** (.500-.710)	703
	03-04	*	< LOD	< LOD	**.250** (.170-.310)	**.330** (.260-.470)	699
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	**3.16** (<LOD-3.53)	912
	01-02	*	< LOD	< LOD	**.630** (<LOD-.740)	**.910** (.770-1.06)	1216
	03-04	*	< LOD	< LOD	< LOD	**.480** (.420-.530)	1088

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Diethyl Phthalate

CAS No. 84-66-2

General Information

Diethyl phthalate (DEP) is a solvent used in many consumer products, particularly those containing fragrances. Products that may contain DEP include perfumes, colognes, deodorants, soaps, shampoos, and hand lotions. People exposed to DEP eliminate mono-ethyl phthalate (MEP) in their urine. Workplace air guidelines for external exposure to DEP have been established by ACGIH and NIOSH. Neither IARC nor NTP has evaluated DEP with respect to human carcinogenicity.

Biomonitoring Information

MEP levels in the NHANES 1999-2000, 2001-2002, and 2003-2004 subsamples were similar to median or geometric mean levels in small samples of pregnant women in New York City (Adibi et al., 2003) and African-American women in Washington, DC (Hoppin et al., 2002), and also in men attending a Boston infertility clinic (Hauser et al., 2007). In contrast, a sample of young Swedish males entering the military had median urinary MEP levels that were somewhat higher than males in the NHANES subsamples. A small study of children less than 2 years old reported mean urine MEP levels that were about twice as high as levels in children (aged 6-11 years) in NHANES 2001-

Urinary Mono-ethyl phthalate (MEP)

Metabolite of Diethyl phthalate (DEP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**179** (156-204)	**164** (136-201)	**454** (370-538)	**1260** (1010-1480)	**2840** (2150-3770)	2536
	01-02	**178** (159-199)	**169** (141-194)	**465** (415-527)	**1230** (1040-1440)	**2500** (1860-3220)	2782
	03-04	**193** (169-220)	**174** (151-208)	**502** (457-555)	**1380** (1170-1750)	**2700** (2160-3310)	2605
Age group							
6-11 years	99-00	**91.3** (74.8-111)	**75.4** (62.1-93.7)	**197** (129-249)	**378** (290-730)	**756** (379-1070)	328
	01-02	**85.1** (71.2-102)	**71.9** (61.9-92.5)	**183** (142-217)	**451** (315-636)	**808** (572-1090)	393
	03-04	**95.3** (82.3-110)	**81.7** (70.3-103)	**196** (170-241)	**521** (295-571)	**827** (542-1440)	342
12-19 years	99-00	**211** (160-278)	**193** (141-256)	**564** (419-818)	**1510** (1050-2150)	**3260** (1550-4420)	752
	01-02	**197** (159-243)	**184** (148-227)	**479** (387-651)	**1260** (983-1480)	**2070** (1470-3050)	742
	03-04	**225** (187-270)	**221** (165-294)	**557** (432-695)	**1250** (973-1560)	**2310** (1360-3310)	729
20 years and older	99-00	**190** (164-219)	**180** (140-221)	**482** (390-590)	**1340** (1010-1660)	**3480** (2230-4640)	1456
	01-02	**191** (171-214)	**181** (152-212)	**498** (441-567)	**1350** (1060-1660)	**2720** (2160-3670)	1647
	03-04	**205** (176-238)	**188** (158-219)	**533** (471-629)	**1590** (1220-2070)	**2980** (2250-3800)	1534
Gender							
Males	99-00	**179** (149-215)	**154** (119-197)	**523** (372-650)	**1440** (1020-2280)	**3500** (2130-4560)	1214
	01-02	**182** (157-211)	**171** (139-199)	**502** (419-603)	**1450** (1060-2110)	**3100** (2110-4390)	1371
	03-04	**197** (173-224)	**171** (148-201)	**536** (449-654)	**1520** (1210-2070)	**2910** (2210-3480)	1250
Females	99-00	**178** (154-206)	**174** (138-210)	**425** (350-508)	**988** (880-1230)	**2230** (1370-3880)	1322
	01-02	**174** (153-198)	**167** (139-194)	**427** (387-498)	**1050** (879-1310)	**1860** (1490-2500)	1411
	03-04	**189** (160-225)	**182** (138-219)	**478** (392-564)	**1260** (969-1640)	**2590** (1800-3420)	1355
Race/ethnicity							
Mexican Americans	99-00	**181** (157-209)	**174** (146-210)	**441** (390-541)	**1280** (851-1510)	**1720** (1460-2130)	813
	01-02	**226** (195-262)	**220** (190-264)	**530** (444-660)	**1490** (1050-2110)	**2630** (1540-4460)	677
	03-04	**267** (239-298)	**249** (212-307)	**597** (523-688)	**1640** (1320-2180)	**3050** (2230-4300)	652
Non-Hispanic blacks	99-00	**322** (275-377)	**306** (256-350)	**789** (635-949)	**1890** (1410-2270)	**3610** (2130-4640)	603
	01-02	**352** (324-384)	**357** (290-407)	**853** (709-1090)	**2160** (1620-2470)	**3540** (2810-5070)	703
	03-04	**357** (310-412)	**306** (253-414)	**948** (769-1150)	**2500** (1840-2980)	**4370** (2780-5910)	699
Non-Hispanic whites	99-00	**152** (133-175)	**134** (108-157)	**367** (287-482)	**986** (798-1340)	**2470** (1590-3880)	908
	01-02	**158** (141-178)	**147** (119-177)	**413** (366-451)	**1020** (905-1230)	**2320** (1560-2720)	1216
	03-04	**167** (145-193)	**148** (125-175)	**418** (366-477)	**1210** (954-1480)	**2250** (1590-3290)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 1.2, 0.9, and 0.4, respectively.

2002 (Brock et al., 2002). Median MEP levels found in a small sample of German residents (Koch et al., 2003) were slightly lower than levels found in NHANES 2001-2002.

In an analysis of NHANES 1999-2000, the adjusted geometric mean levels of urinary MEP were lower in the group aged 6-11 years than in either of the other age groups. This age-related trend is opposite the direction seen for other phthalates. Other population estimates also differed by sex and race ethnicity (Silva et al., 2004). Analysis of NHANES 2001-2002 showed similar findings, with adjusted geometric mean levels of urinary MEP that increased with age (CDC, 2005).

Finding a measurable amount of MEP in urine does not mean that the levels of MEP or the parent compound cause an adverse health effect. Biomonitoring studies on levels of MEP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DEP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-ethyl phthalate (MEP) (creatinine corrected)

Metabolite of Diethyl phthalate (DEP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**163** (149-178)	**141** (129-157)	**360** (307-422)	**905** (753-1180)	**1950** (1670-2310)	2536
	01-02	**167** (150-185)	**148** (133-162)	**388** (330-435)	**969** (805-1180)	**1840** (1450-2200)	2782
	03-04	**181** (163-202)	**153** (137-177)	**452** (386-504)	**1110** (889-1290)	**2040** (1640-2540)	2605
Age group							
6-11 years	99-00	**92.6** (77.9-110)	**79.6** (65.7-110)	**165** (127-208)	**341** (219-554)	**625** (400-784)	328
	01-02	**96.9** (82.5-114)	**81.2** (66.3-105)	**177** (135-224)	**512** (290-802)	**843** (512-1320)	393
	03-04	**101** (87.0-117)	**87.0** (66.5-113)	**180** (145-203)	**470** (310-596)	**719** (470-1330)	342
12-19 years	99-00	**142** (119-169)	**122** (93.0-156)	**364** (275-495)	**879** (676-1260)	**1760** (1000-2000)	752
	01-02	**152** (126-184)	**140** (111-180)	**330** (249-409)	**808** (590-1100)	**1330** (868-1840)	742
	03-04	**168** (141-201)	**150** (123-184)	**363** (292-485)	**791** (589-1080)	**1470** (987-2220)	729
20 years and older	99-00	**179** (161-199)	**154** (136-177)	**390** (336-452)	**1010** (803-1460)	**2170** (1790-3350)	1456
	01-02	**181** (164-200)	**160** (146-182)	**419** (363-486)	**1060** (884-1320)	**2120** (1520-2790)	1647
	03-04	**197** (174-223)	**177** (147-202)	**512** (423-632)	**1230** (989-1610)	**2290** (1770-3200)	1534
Gender							
Males	99-00	**141** (124-159)	**120** (107-134)	**324** (249-415)	**1000** (693-1480)	**1950** (1460-2900)	1214
	01-02	**148** (130-168)	**126** (110-147)	**352** (282-425)	**1100** (839-1480)	**2120** (1490-3030)	1371
	03-04	**154** (139-171)	**127** (108-150)	**390** (341-465)	**1070** (852-1360)	**2000** (1610-2410)	1250
Females	99-00	**187** (165-211)	**158** (142-179)	**377** (307-495)	**822** (697-1170)	**1930** (1170-3410)	1322
	01-02	**187** (166-210)	**171** (148-188)	**407** (355-473)	**860** (712-1100)	**1430** (1190-2010)	1411
	03-04	**211** (180-248)	**181** (148-217)	**508** (379-634)	**1120** (889-1400)	**2250** (1440-3330)	1355
Race/ethnicity							
Mexican Americans	99-00	**164** (142-190)	**154** (136-174)	**382** (314-472)	**814** (673-974)	**1330** (974-1920)	813
	01-02	**213** (182-249)	**199** (164-242)	**461** (396-572)	**1080** (860-1650)	**1940** (1410-2630)	677
	03-04	**241** (213-271)	**233** (202-270)	**533** (417-665)	**1230** (956-1610)	**2270** (1810-3140)	652
Non-Hispanic blacks	99-00	**208** (183-236)	**196** (166-228)	**443** (390-505)	**1030** (762-1700)	**1920** (1230-2590)	603
	01-02	**247** (226-271)	**227** (185-270)	**557** (478-618)	**1240** (961-1480)	**2090** (1550-2800)	703
	03-04	**254** (225-287)	**212** (188-246)	**619** (476-791)	**1530** (1200-1970)	**2590** (2160-3500)	699
Non-Hispanic whites	99-00	**149** (135-165)	**128** (111-142)	**313** (239-387)	**856** (655-1390)	**1950** (1480-2740)	908
	01-02	**157** (142-173)	**136** (124-150)	**338** (288-402)	**919** (712-1160)	**1590** (1320-2170)	1216
	03-04	**165** (144-189)	**135** (120-158)	**386** (338-485)	**989** (831-1330)	**1920** (1400-2780)	1088

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Di-2-ethylhexyl Phthalate

CAS No. 117-81-7

General Information

Di-2-ethylhexyl phthalate (DEHP) is primarily used to produce flexibility in plastics, mainly polyvinyl chloride, which is used for many consumer products, toys, packaging film, and blood product storage and intravenous delivery systems. Concentrations in plastic materials may reach 40% by weight. DEHP has been removed from or replaced in most toys and food packaging in the United States.

Following ingestion, DEHP is metabolized to more than 30 metabolites which are rapidly eliminated in urine, and in humans, as glucuronide conjugates (Albro et al., 1982; Albro and Lavenhar, 1989; ATSDR, 2002; Peck and Albro,1982). Four metabolites were measured in this *Report*: mono-(2-ethyl-5-hexyl) phthalate (MEHP), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP), mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP) and mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP).

MEHP is primarily formed by the hydrolysis of DEHP in the gastrointestinal tract and then absorbed. DEHP present in medical devices and parenteral delivery systems results in the diester rather than the monoester form being directly introduced into the blood. After parenteral administration,

Urinary Mono-2-ethylhexyl phthalate (MEHP)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**3.43** (3.19-3.69)	**3.20** (3.00-3.60)	**7.60** (6.80-8.40)	**14.9** (13.5-17.4)	**23.8** (19.2-28.6)	2541
	01-02	**4.27** (3.80-4.79)	**4.20** (3.70-4.90)	**9.80** (8.40-11.6)	**23.0** (19.1-27.9)	**39.2** (31.8-50.0)	2782
	03-04	**2.34** (2.10-2.62)	**1.90** (1.70-2.40)	**5.30** (4.50-6.60)	**15.1** (11.4-20.6)	**31.0** (21.4-42.0)	2605
Age group							
6-11 years	99-00	**5.12** (4.42-5.92)	**4.90** (3.70-6.40)	**11.1** (8.30-13.6)	**19.0** (13.8-36.1)	**35.3** (15.6-130)	328
	01-02	**4.41** (3.90-5.00)	**4.40** (4.10-5.30)	**9.30** (7.90-11.7)	**19.7** (14.6-25.9)	**31.4** (21.8-47.9)	393
	03-04	**2.84** (2.10-3.84)	**2.70** (1.80-4.10)	**6.40** (4.40-9.60)	**13.9** (7.80-27.6)	**27.6** (11.3-64.7)	342
12-19 years	99-00	**3.75** (3.24-4.35)	**3.70** (2.90-4.60)	**8.10** (6.40-9.40)	**15.3** (11.4-20.5)	**22.8** (19.1-29.2)	752
	01-02	**4.57** (3.96-5.27)	**4.50** (3.70-5.10)	**11.0** (9.50-14.4)	**23.0** (17.7-32.7)	**42.5** (25.9-57.5)	742
	03-04	**2.77** (2.25-3.41)	**2.50** (2.00-3.00)	**6.40** (4.50-8.60)	**18.6** (10.2-35.6)	**40.6** (20.7-58.4)	729
20 years and older	99-00	**3.21** (2.94-3.51)	**3.00** (2.70-3.40)	**7.30** (6.40-8.00)	**14.5** (12.1-17.0)	**22.7** (17.5-27.0)	1461
	01-02	**4.20** (3.63-4.86)	**4.10** (3.50-5.00)	**9.50** (8.10-11.9)	**23.5** (18.0-29.8)	**39.5** (30.3-57.1)	1647
	03-04	**2.23** (2.03-2.44)	**1.70** (1.50-2.00)	**5.10** (4.50-6.00)	**15.1** (10.9-19.7)	**29.5** (20.4-40.0)	1534
Gender							
Males	99-00	**3.68** (3.31-4.10)	**3.40** (2.90-3.90)	**8.00** (7.40-8.80)	**16.0** (14.0-19.0)	**25.3** (19.5-36.7)	1215
	01-02	**4.31** (3.84-4.83)	**4.30** (3.70-5.10)	**9.70** (8.30-11.2)	**23.0** (16.9-29.8)	**37.9** (29.9-48.4)	1371
	03-04	**2.56** (2.26-2.90)	**2.20** (1.70-2.60)	**6.00** (4.60-7.70)	**17.2** (11.3-26.3)	**33.3** (24.9-55.5)	1250
Females	99-00	**3.21** (2.91-3.54)	**3.10** (2.80-3.50)	**7.10** (5.90-8.50)	**13.6** (12.1-17.2)	**21.9** (15.6-28.5)	1326
	01-02	**4.23** (3.67-4.86)	**4.10** (3.50-5.00)	**9.80** (8.40-12.2)	**23.0** (19.5-28.4)	**43.5** (31.4-53.7)	1411
	03-04	**2.15** (1.92-2.42)	**1.80** (1.50-2.10)	**4.90** (4.10-5.70)	**13.2** (10.0-18.1)	**27.8** (17.5-40.7)	1355
Race/ethnicity							
Mexican Americans	99-00	**3.49** (3.16-3.85)	**3.50** (3.10-3.90)	**7.00** (5.70-8.60)	**13.3** (10.7-18.7)	**23.9** (17.4-27.3)	814
	01-02	**4.32** (3.75-4.98)	**4.70** (3.80-5.70)	**10.1** (8.50-11.4)	**19.6** (16.6-23.0)	**28.5** (24.2-39.9)	677
	03-04	**2.35** (1.87-2.96)	**2.20** (1.50-3.00)	**5.10** (4.30-6.60)	**11.2** (7.50-16.5)	**18.5** (11.6-38.2)	652
Non-Hispanic blacks	99-00	**4.82** (3.92-5.93)	**5.20** (4.10-5.80)	**9.50** (7.60-11.4)	**19.5** (12.9-26.5)	**29.5** (18.6-60.3)	603
	01-02	**6.60** (5.57-7.82)	**6.70** (5.40-8.10)	**15.4** (13.0-18.7)	**32.9** (26.5-41.4)	**52.6** (41.0-84.0)	703
	03-04	**3.61** (3.07-4.23)	**3.50** (3.00-4.00)	**8.50** (7.10-11.4)	**22.9** (16.5-28.6)	**35.2** (29.3-49.1)	699
Non-Hispanic whites	99-00	**3.16** (2.89-3.46)	**2.80** (2.50-3.10)	**7.40** (6.30-8.40)	**14.5** (12.2-17.4)	**22.4** (16.9-28.5)	912
	01-02	**3.85** (3.37-4.40)	**3.70** (3.10-4.40)	**8.70** (7.80-9.90)	**20.9** (17.3-25.9)	**37.9** (29.9-49.5)	1216
	03-04	**2.14** (1.92-2.39)	**1.70** (1.40-1.90)	**4.80** (4.00-5.80)	**13.6** (9.50-20.0)	**31.0** (18.1-48.9)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 1.2, 1.0, and 0.9, respectively.

hydrolysis of DEHP most likely also occurs in the blood, and subsequent metabolism is similar to that following ingestion (Koch et al., 2005*a*, 2005*b*, 2005*c*). MEOHP, MEHHP, and MECPP are produced by the oxidative metabolism of MEHP and are present at roughly three- to five-fold higher concentrations than MEHP in urine (Barr et al., 2003; Fromme et al., 2007; Koch et al., 2003).

MEHP is the putative toxic metabolite of DEHP. Liver toxicity, decreased testicular weight, and testicular atrophy have been observed in rodents fed high doses over a short term or with chronic dosing (McKee et al., 2004; NTP-CERHR, 2000*c*, 2006). In contrast, marmoset monkeys fed high dose DEHP for longer than a year did not demonstrate testicular or liver toxicity (NTP-CERHR, 2006). Very high doses of DEHP have suppressed estradiol production in female rats (Lovecamp-Swan and Davis, 2003). The Food and Drug Administration determined that in adults, the amounts of DEHP or MEHP received from intravenous delivery systems or blood transfusions (DEHP is hydrolyzed to MEHP in stored blood) would result in short-term elevations similar to background levels (FDA, 2001). However, critically ill neonates and infants receiving selected or multiple intensive procedures, such as exchange transfusions, extracorporeal membrane oxygenation, and parenteral nutrition, could receive higher exposures than the general population (Calafat et al., 2004; FDA, 2001; Loff et al., 2000; Weuve et al., 2006).

Urinary Mono-2-ethylhexyl phthalate (MEHP) (creatinine corrected)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**3.12** (2.95-3.31)	**3.08** (2.82-3.27)	**5.88** (5.38-6.25)	**10.8** (9.62-12.5)	**18.9** (15.0-21.8)	2541
	01-02	**4.00** (3.58-4.48)	**3.90** (3.44-4.47)	**7.94** (7.22-9.02)	**18.0** (15.3-21.5)	**32.8** (25.2-42.9)	2782
	03-04	**2.20** (2.01-2.41)	**1.89** (1.68-2.19)	**4.31** (3.84-4.74)	**10.8** (8.72-13.8)	**25.4** (16.7-34.7)	2605
Age group							
6-11 years	99-00	**5.19** (4.55-5.93)	**5.37** (4.52-5.95)	**9.11** (8.06-11.4)	**21.6** (11.5-41.9)	**41.9** (13.5-86.2)	328
	01-02	**5.03** (4.47-5.65)	**5.38** (4.51-6.21)	**9.90** (7.87-11.5)	**21.1** (13.8-28.8)	**31.4** (24.3-40.7)	393
	03-04	**3.00** (2.30-3.93)	**2.80** (1.93-4.09)	**5.86** (4.69-7.70)	**14.3** (8.54-24.4)	**28.7** (14.1-45.3)	342
12-19 years	99-00	**2.53** (2.14-2.99)	**2.35** (2.05-2.76)	**5.83** (4.38-6.29)	**9.66** (7.41-11.5)	**12.1** (10.5-17.3)	752
	01-02	**3.53** (3.09-4.03)	**3.67** (2.89-4.48)	**7.47** (6.51-8.67)	**15.2** (11.7-21.9)	**25.2** (17.7-32.8)	742
	03-04	**2.07** (1.74-2.48)	**1.88** (1.60-2.23)	**4.25** (3.19-5.62)	**11.6** (6.83-23.2)	**24.8** (11.6-37.9)	729
20 years and older	99-00	**3.03** (2.83-3.25)	**2.98** (2.73-3.23)	**5.55** (4.90-6.06)	**10.0** (8.60-12.9)	**17.5** (13.8-22.1)	1461
	01-02	**3.97** (3.49-4.52)	**3.82** (3.26-4.38)	**7.79** (7.00-9.00)	**18.3** (15.3-21.8)	**34.5** (23.1-47.9)	1647
	03-04	**2.14** (1.98-2.31)	**1.84** (1.63-2.08)	**4.14** (3.78-4.40)	**10.5** (8.38-12.9)	**25.6** (15.9-36.3)	1534
Gender							
Males	99-00	**2.89** (2.60-3.22)	**2.76** (2.52-2.96)	**5.58** (4.71-6.08)	**10.3** (9.35-12.4)	**21.6** (14.1-27.7)	1215
	01-02	**3.50** (3.08-3.99)	**3.33** (2.83-3.90)	**7.00** (6.49-7.77)	**16.2** (12.8-20.9)	**31.6** (20.5-49.4)	1371
	03-04	**2.01** (1.82-2.21)	**1.71** (1.46-1.89)	**4.14** (3.49-4.81)	**10.4** (7.68-16.2)	**23.3** (15.1-41.1)	1250
Females	99-00	**3.36** (3.11-3.63)	**3.33** (2.91-3.80)	**6.15** (5.55-6.77)	**11.1** (9.11-14.0)	**17.3** (12.4-24.6)	1326
	01-02	**4.54** (4.02-5.13)	**4.47** (3.85-5.14)	**9.28** (7.94-10.3)	**20.3** (16.6-24.4)	**34.7** (27.1-42.0)	1411
	03-04	**2.40** (2.15-2.69)	**2.16** (1.84-2.40)	**4.40** (3.97-4.89)	**10.9** (8.27-16.0)	**27.0** (17.5-34.6)	1355
Race/ethnicity							
Mexican Americans	99-00	**3.16** (2.72-3.68)	**3.15** (2.52-3.81)	**5.88** (4.86-7.24)	**11.6** (9.63-13.1)	**15.7** (12.6-23.1)	814
	01-02	**4.07** (3.60-4.61)	**4.18** (3.82-4.90)	**7.80** (6.64-9.49)	**16.4** (13.6-18.9)	**24.9** (19.8-28.7)	677
	03-04	**2.12** (1.74-2.59)	**1.94** (1.50-2.42)	**4.06** (3.29-4.93)	**9.38** (5.72-15.4)	**16.8** (9.86-38.6)	652
Non-Hispanic blacks	99-00	**3.11** (2.59-3.73)	**3.13** (2.50-3.61)	**5.84** (4.43-7.32)	**10.2** (8.05-15.6)	**18.4** (11.6-35.2)	603
	01-02	**4.63** (3.96-5.42)	**4.59** (3.97-5.02)	**9.93** (7.95-12.4)	**21.2** (16.0-33.2)	**39.9** (27.7-48.1)	703
	03-04	**2.56** (2.24-2.92)	**2.28** (2.02-2.78)	**5.17** (4.48-6.83)	**13.2** (10.5-16.2)	**27.5** (18.4-36.0)	699
Non-Hispanic whites	99-00	**3.09** (2.84-3.36)	**3.08** (2.73-3.47)	**5.87** (5.11-6.67)	**10.6** (8.95-13.5)	**20.0** (14.0-24.6)	912
	01-02	**3.81** (3.34-4.35)	**3.67** (3.11-4.33)	**7.78** (6.74-9.35)	**17.0** (14.1-21.8)	**32.8** (21.5-46.9)	1216
	03-04	**2.12** (1.91-2.35)	**1.82** (1.60-2.13)	**4.11** (3.49-4.42)	**10.7** (7.42-15.1)	**27.0** (15.1-37.4)	1088

OSHA has established a workplace air standard for external exposure to DEHP; NIOSH and ACGIH have established guidelines for workplace air exposure to DEHP. IARC considers DEHP to be unclassifiable with respect to human carcinogenicity. NTP determined that DEHP is reasonably anticipated to be a human carcinogen.

Biomonitoring Information

The levels of MEHP reported in NHANES 1999-2000, 2001-2002, and 2003-2004 appear roughly comparable to those reported previously in several small U.S. studies involving adults (Blount et al., 2000), pregnant women in New York City (Adibi et al., 2003), and low income African-American women in Washington, DC (Hoppin et al., 2002). In contrast, a sample of South Korean women had higher urine MEHP levels: the geometric mean was about ten times higher than for females in each of the NHANES survey periods (Koo and Lee, 2005; CDC, 2005). Median urine MEHP levels in a small group of Japanese adults, in a group of Swedish male military recruits, and in samples of men attending an infertility clinic were similar to median values for adults and males, respectively, in NHANES 1999-2000 and 2001-2002 subsamples (Duty et al., 2004, 2005; Itoh et al., 2005).

In another sample of men attending an infertility clinic, the median and 95th percentile values of urinary MEHP were similar, but MEHHP and MEOHP were about three to five times higher than comparable values found in males in two NHANES survey periods (1999-2000, 2001-2002) (CDC, 2005; Hauser et al., 2007). Compared with the U.S. population in this *Report,* urinary MEHP, MEOHP, and MEHHP levels were similar or up to twofold higher in a sample of German residents (Koch et al., 2003; Preuss et al., 2005) and German children (Becker et al., 2004; Koch et al., 2004). During 2001-2003, median levels of urinary MEOHP and MEHHP appeared to be similar in samples of German university students and the adults in this *Report* (Wittasek et al., 2007).

In separate analyses of NHANES 1999-2000 and NHANES 2001-2002, the adjusted geometric mean levels of urinary MEHP were significantly higher in children compared with adolescents and adults, and in females compared with males (CDC, 2005; Silva et al., 2004). South Korean children had geometric mean urine MEHP levels that were about three times higher than the U.S. children in this *Report* (Koo and

Urinary Mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**20.0** (17.8-22.5)	**20.1** (17.8-22.4)	**43.6** (38.0-49.7)	**92.3** (77.0-108)	**192** (131-256)	2782
	03-04	**21.7** (19.3-24.4)	**21.2** (18.7-24.1)	**49.1** (40.5-56.9)	**121** (91.3-164)	**266** (165-383)	2605
Age group							
6-11 years	01-02	**33.6** (29.7-37.9)	**32.9** (26.9-39.1)	**66.9** (49.7-74.0)	**127** (103-148)	**216** (137-280)	393
	03-04	**36.9** (28.4-47.9)	**36.5** (26.5-47.0)	**77.4** (49.1-103)	**164** (79.9-350)	**318** (164-400)	342
12-19 years	01-02	**24.9** (21.3-29.1)	**25.3** (22.9-31.3)	**50.6** (40.7-64.5)	**107** (78.5-148)	**216** (117-330)	742
	03-04	**28.3** (23.0-34.8)	**29.8** (25.9-33.9)	**56.9** (45.4-73.7)	**157** (84.1-299)	**317** (176-553)	729
20 years and older	01-02	**18.1** (15.7-20.9)	**17.8** (14.7-20.7)	**39.8** (32.7-48.0)	**86.2** (65.7-107)	**175** (110-279)	1647
	03-04	**19.5** (17.7-21.5)	**18.4** (16.6-21.0)	**41.9** (36.9-51.2)	**107** (88.2-136)	**225** (148-384)	1534
Gender							
Males	01-02	**22.0** (19.5-24.7)	**21.2** (19.4-24.2)	**48.0** (41.4-54.4)	**94.2** (80.8-110)	**212** (130-256)	1371
	03-04	**24.1** (20.9-27.9)	**22.9** (19.2-27.9)	**51.0** (40.5-59.8)	**133** (94.8-220)	**317** (162-470)	1250
Females	01-02	**18.3** (15.7-21.4)	**18.2** (14.9-22.1)	**39.8** (34.3-46.0)	**86.0** (69.4-115)	**170** (119-273)	1411
	03-04	**19.7** (17.4-22.2)	**19.4** (16.7-22.8)	**46.4** (37.5-54.4)	**103** (84.1-148)	**214** (140-318)	1355
Race/ethnicity							
Mexican Americans	01-02	**18.5** (16.2-21.1)	**19.1** (16.3-21.6)	**36.3** (31.6-44.0)	**79.9** (66.4-93.9)	**123** (100-161)	677
	03-04	**18.9** (15.4-23.4)	**19.8** (17.6-22.3)	**37.5** (30.0-45.6)	**72.2** (52.4-115)	**116** (71.6-327)	652
Non-Hispanic blacks	01-02	**29.8** (26.1-34.1)	**30.9** (27.2-34.3)	**61.9** (52.6-69.4)	**126** (108-157)	**276** (157-339)	703
	03-04	**30.8** (26.8-35.5)	**29.1** (25.3-32.3)	**65.6** (53.7-76.3)	**154** (113-178)	**275** (174-401)	699
Non-Hispanic whites	01-02	**19.1** (16.7-21.9)	**19.2** (16.9-21.4)	**41.7** (35.3-50.7)	**91.1** (75.6-110)	**212** (130-275)	1216
	03-04	**20.8** (18.6-23.3)	**19.7** (17.2-22.5)	**47.5** (39.4-56.1)	**120** (91.3-165)	**270** (155-403)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 1.0 and 0.3.

Lee, 2005). Younger children eliminate higher proportions of urinary MEHHP and MEOHP relative to MEHP, with the difference increasing as age decreases; this may be the result of differences in metabolism and/or excretion (NTP-CERHR, 2006). Studies of hospitalized neonates have reported urinary geometric mean levels of MEHP, MEOHP, and MEHHP that were two to five times higher, or more (depending on the intensity of DEHP-product exposure), than the geometric means of children in the NHANES subsamples for all three survey periods (Calafat et al., 2004; Weuve et al., 2006). Small studies of plasma and platelet donors have reported very high levels of MEHP, MEOHP, MEHHP and MECPP in urine collected shortly after these procedures (Koch et al., 2005*b*, 2005*c*).

Finding a measurable amount of one or more DEHP metabolites in urine does not mean that the levels of the metabolites or the parent compound cause an adverse health effect. Biomonitoring studies on levels of urinary DEHP metabolites provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DEHP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP) (creatinine corrected)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**18.8** (17.0-20.7)	**16.6** (14.9-18.5)	**32.2** (27.8-37.1)	**71.1** (58.7-88.3)	**143** (101-200)	2782
	03-04	**20.4** (18.7-22.3)	**17.7** (16.3-19.6)	**35.8** (30.5-43.3)	**93.5** (74.0-128)	**182** (134-262)	2605
Age group							
6-11 years	01-02	**38.2** (34.3-42.6)	**34.3** (29.9-38.9)	**60.6** (51.9-76.4)	**107** (96.3-147)	**211** (122-313)	393
	03-04	**39.0** (31.1-48.9)	**36.6** (25.3-49.3)	**65.6** (49.8-91.3)	**129** (77.1-253)	**211** (123-708)	342
12-19 years	01-02	**19.2** (17.0-21.8)	**17.8** (15.6-20.0)	**34.9** (29.2-42.7)	**73.4** (58.4-80.7)	**102** (86.6-160)	742
	03-04	**21.2** (18.1-24.7)	**18.6** (16.9-21.7)	**38.7** (29.7-53.4)	**103** (62.7-209)	**212** (100-358)	729
20 years and older	01-02	**17.1** (15.2-19.3)	**15.0** (13.3-16.7)	**27.7** (23.2-34.0)	**63.7** (48.3-86.9)	**137** (84.4-203)	1647
	03-04	**18.8** (17.5-20.2)	**16.3** (15.4-17.5)	**31.6** (28.1-35.3)	**83.8** (67.2-106)	**171** (129-246)	1534
Gender							
Males	01-02	**17.9** (16.2-19.7)	**15.4** (13.8-17.9)	**32.2** (27.8-36.8)	**73.4** (55.3-91.8)	**137** (97.7-224)	1371
	03-04	**18.9** (17.1-20.9)	**17.1** (15.2-18.6)	**32.7** (26.6-41.6)	**93.4** (68.8-123)	**193** (108-291)	1250
Females	01-02	**19.7** (17.3-22.4)	**17.6** (15.4-19.5)	**32.1** (26.8-38.6)	**70.5** (57.8-93.7)	**156** (93.7-201)	1411
	03-04	**21.9** (19.7-24.5)	**18.7** (16.8-20.9)	**39.3** (33.8-46.9)	**94.3** (72.8-136)	**171** (146-261)	1355
Race/ethnicity							
Mexican Americans	01-02	**17.4** (15.9-19.1)	**15.7** (14.4-17.5)	**30.6** (26.0-34.7)	**65.9** (50.6-83.9)	**103** (75.5-128)	677
	03-04	**17.1** (14.3-20.4)	**15.4** (13.2-17.7)	**29.3** (23.8-36.8)	**57.3** (45.7-97.6)	**105** (70.1-195)	652
Non-Hispanic blacks	01-02	**20.9** (18.8-23.3)	**19.7** (17.5-21.8)	**38.3** (32.1-46.0)	**93.5** (69.2-123)	**164** (130-183)	703
	03-04	**21.9** (20.1-23.8)	**19.5** (17.3-22.6)	**40.1** (35.8-45.3)	**102** (75.5-122)	**164** (133-269)	699
Non-Hispanic whites	01-02	**18.9** (17.0-21.0)	**16.3** (14.8-18.4)	**32.1** (27.3-37.3)	**70.8** (56.9-93.7)	**177** (98.0-242)	1216
	03-04	**20.5** (18.5-22.8)	**17.8** (16.2-19.7)	**35.3** (29.7-44.9)	**96.2** (75.8-136)	**211** (136-283)	1088

Urinary Mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**13.5** (12.0-15.0)	**14.0** (12.5-15.1)	**29.6** (25.2-34.0)	**59.9** (50.4-70.9)	**120** (87.2-156)	2782
	03-04	**14.5** (13.0-16.1)	**14.4** (12.4-16.7)	**31.4** (27.4-36.6)	**76.7** (59.4-102)	**157** (106-232)	2605
Age group							
6-11 years	01-02	**23.3** (20.9-26.1)	**22.9** (18.5-28.1)	**46.5** (38.1-52.0)	**81.6** (64.7-109)	**142** (93.9-178)	393
	03-04	**25.1** (19.6-32.3)	**25.8** (19.3-31.4)	**51.1** (32.1-76.5)	**97.9** (58.8-197)	**197** (97.6-261)	342
12-19 years	01-02	**17.5** (15.1-20.3)	**18.6** (16.2-20.7)	**35.0** (27.7-42.1)	**70.7** (52.2-104)	**118** (74.0-174)	742
	03-04	**19.5** (16.0-23.7)	**20.3** (18.4-23.5)	**37.8** (32.6-44.6)	**110** (54.6-168)	**212** (103-326)	729
20 years and older	01-02	**12.0** (10.5-13.9)	**12.3** (10.4-14.1)	**26.0** (21.6-32.1)	**52.3** (41.8-68.3)	**116** (74.9-160)	1647
	03-04	**12.9** (11.8-14.1)	**12.4** (10.9-14.5)	**27.0** (25.0-30.9)	**68.9** (55.0-86.5)	**139** (92.7-216)	1534
Gender							
Males	01-02	**14.5** (13.0-16.2)	**14.6** (13.1-16.2)	**31.6** (25.6-34.7)	**60.4** (52.3-71.4)	**129** (84.4-167)	1371
	03-04	**15.6** (13.6-17.9)	**14.7** (12.7-18.1)	**31.8** (27.2-39.5)	**83.8** (59.4-134)	**185** (96.2-277)	1250
Females	01-02	**12.5** (10.8-14.6)	**13.1** (11.2-15.0)	**28.1** (23.7-33.5)	**57.5** (45.8-72.7)	**115** (81.8-147)	1411
	03-04	**13.4** (11.9-15.1)	**13.7** (11.4-16.4)	**29.5** (26.1-36.6)	**68.6** (53.7-88.1)	**143** (88.2-210)	1355
Race/ethnicity							
Mexican Americans	01-02	**13.1** (11.6-14.9)	**13.4** (11.6-15.0)	**25.5** (21.6-30.8)	**56.6** (40.6-70.3)	**77.3** (70.5-101)	677
	03-04	**12.8** (10.5-15.5)	**13.6** (11.4-15.6)	**25.3** (20.4-29.9)	**46.6** (32.3-70.8)	**76.0** (51.6-153)	652
Non-Hispanic blacks	01-02	**19.6** (17.1-22.5)	**20.1** (17.9-22.4)	**39.0** (34.8-44.2)	**80.5** (71.4-97.4)	**153** (102-228)	703
	03-04	**20.2** (17.7-23.0)	**20.1** (17.0-22.5)	**40.0** (33.9-46.9)	**92.6** (68.8-130)	**173** (104-247)	699
Non-Hispanic whites	01-02	**12.8** (11.2-14.6)	**13.2** (11.6-14.6)	**28.5** (23.6-34.0)	**58.6** (48.8-70.9)	**126** (83.7-172)	1216
	03-04	**13.8** (12.4-15.4)	**13.4** (11.3-16.3)	**31.0** (27.0-36.3)	**77.6** (59.4-102)	**161** (98.7-241)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 1.1 and 0.5.

Urinary Mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP) (creatinine corrected)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**12.6** (11.5-13.9)	**11.2** (10.2-12.3)	**21.3** (18.3-23.8)	**45.2** (37.1-58.1)	**87.0** (68.0-124)	2782
	03-04	**13.6** (12.4-14.8)	**12.1** (11.0-12.9)	**24.3** (20.9-27.8)	**63.0** (47.8-75.8)	**118** (94.1-153)	2605
Age group							
6-11 years	01-02	**26.6** (24.0-29.4)	**22.8** (20.3-25.0)	**43.3** (33.6-47.1)	**74.7** (69.0-91.9)	**131** (83.0-183)	393
	03-04	**26.6** (21.4-33.0)	**25.3** (17.8-32.4)	**43.6** (34.2-63.2)	**77.1** (63.0-118)	**121** (76.3-435)	342
12-19 years	01-02	**13.5** (12.0-15.2)	**12.0** (10.8-14.3)	**23.4** (20.0-28.5)	**48.4** (39.2-54.9)	**70.5** (55.0-97.2)	742
	03-04	**14.6** (12.6-16.9)	**12.7** (11.6-14.4)	**25.5** (20.7-33.8)	**67.9** (42.3-143)	**153** (61.8-209)	729
20 years and older	01-02	**11.4** (10.2-12.8)	**10.1** (8.89-11.4)	**17.5** (15.2-21.8)	**38.4** (30.5-52.5)	**84.3** (53.3-128)	1647
	03-04	**12.4** (11.5-13.3)	**11.0** (10.0-12.0)	**20.9** (18.6-22.8)	**53.9** (40.7-70.2)	**109** (88.6-130)	1534
Gender							
Males	01-02	**11.8** (10.7-13.0)	**10.2** (8.93-11.7)	**21.2** (18.5-23.3)	**46.1** (35.3-58.7)	**84.2** (69.6-104)	1371
	03-04	**12.3** (11.1-13.5)	**11.1** (10.0-12.0)	**21.6** (17.6-26.9)	**59.1** (45.4-72.0)	**120** (72.0-162)	1250
Females	01-02	**13.5** (11.9-15.2)	**12.0** (10.8-13.7)	**21.5** (18.0-25.6)	**44.8** (36.8-61.6)	**92.3** (61.0-139)	1411
	03-04	**14.9** (13.4-16.7)	**12.7** (11.4-14.2)	**26.6** (21.8-30.6)	**65.6** (48.0-90.1)	**118** (97.0-157)	1355
Race/ethnicity							
Mexican Americans	01-02	**12.4** (11.4-13.5)	**11.0** (10.5-12.3)	**20.9** (18.5-24.4)	**44.6** (33.4-56.2)	**65.9** (53.1-83.1)	677
	03-04	**11.5** (9.81-13.6)	**10.7** (9.04-12.3)	**18.8** (15.6-24.6)	**39.1** (31.8-53.9)	**63.0** (47.2-121)	652
Non-Hispanic blacks	01-02	**13.8** (12.3-15.4)	**13.1** (12.0-14.2)	**23.9** (20.0-29.3)	**58.3** (45.3-79.7)	**101** (81.3-124)	703
	03-04	**14.3** (13.1-15.6)	**13.3** (11.3-15.5)	**24.8** (21.7-27.7)	**61.2** (46.8-76.6)	**105** (79.7-152)	699
Non-Hispanic whites	01-02	**12.7** (11.4-14.0)	**11.1** (9.90-12.3)	**20.8** (18.0-23.9)	**45.7** (35.9-64.9)	**96.0** (68.5-161)	1216
	03-04	**13.7** (12.2-15.3)	**12.0** (10.5-12.9)	**24.9** (20.7-28.6)	**69.5** (51.4-95.3)	**124** (90.3-182)	1088

Urinary Mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**34.7** (31.0-38.9)	**33.0** (29.1-37.4)	**71.8** (61.7-84.8)	**168** (133-240)	**339** (235-506)	2605
Age group							
6-11 years	03-04	**58.2** (44.7-75.6)	**51.6** (39.2-67.6)	**112** (71.4-182)	**314** (124-524)	**391** (238-781)	342
12-19 years	03-04	**44.6** (36.8-54.0)	**42.7** (38.4-47.6)	**86.5** (67.3-108)	**220** (120-397)	**448** (235-808)	729
20 years and older	03-04	**31.3** (28.6-34.4)	**29.2** (26.2-33.0)	**63.5** (56.5-73.9)	**157** (130-187)	**312** (199-457)	1534
Gender							
Males	03-04	**37.9** (33.1-43.5)	**34.7** (30.0-39.5)	**73.7** (60.8-91.9)	**187** (133-300)	**388** (222-660)	1250
Females	03-04	**31.9** (28.1-36.2)	**31.3** (27.5-35.8)	**69.3** (58.9-81.9)	**154** (128-199)	**312** (182-441)	1355
Race/ethnicity							
Mexican Americans	03-04	**31.9** (27.1-37.6)	**31.5** (26.8-37.4)	**57.4** (45.9-71.8)	**116** (86.0-162)	**175** (133-355)	652
Non-Hispanic blacks	03-04	**42.6** (37.0-49.2)	**38.3** (33.8-46.9)	**82.5** (68.7-103)	**191** (146-246)	**339** (244-468)	699
Non-Hispanic whites	03-04	**33.8** (30.1-37.9)	**32.1** (27.6-37.5)	**72.4** (62.0-87.7)	**167** (133-240)	**354** (220-560)	1088

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.

Urinary Mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP) (creatinine corrected)

Metabolite of Di-2-ethylhexyl phthalate (DEHP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**32.6** (29.6-36.0)	**27.0** (24.3-30.6)	**54.6** (48.0-63.5)	**139** (109-186)	**251** (192-356)	2605
Age group							
6-11 years	03-04	**61.5** (49.0-77.2)	**52.2** (41.6-73.8)	**104** (74.2-140)	**210** (111-500)	**372** (192-988)	342
12-19 years	03-04	**33.4** (28.7-38.7)	**27.1** (23.9-32.0)	**55.0** (43.8-83.8)	**168** (92.5-289)	**294** (159-387)	729
20 years and older	03-04	**30.1** (27.7-32.7)	**25.1** (22.9-27.6)	**49.1** (44.1-55.2)	**126** (101-154)	**237** (191-315)	1534
Gender							
Males	03-04	**29.8** (26.8-33.1)	**23.5** (21.4-27.1)	**50.7** (42.2-61.7)	**132** (98.0-191)	**248** (159-422)	1250
Females	03-04	**35.5** (31.6-40.0)	**30.6** (26.4-35.5)	**58.3** (48.8-71.8)	**144** (108-192)	**251** (192-349)	1355
Race/ethnicity							
Mexican Americans	03-04	**28.8** (25.4-32.6)	**24.7** (22.4-26.3)	**46.7** (39.0-56.3)	**94.7** (73.2-137)	**152** (118-238)	652
Non-Hispanic blacks	03-04	**30.3** (27.7-33.2)	**27.0** (23.2-30.7)	**51.1** (41.6-64.0)	**135** (100-161)	**212** (173-252)	699
Non-Hispanic whites	03-04	**33.4** (29.5-37.7)	**27.0** (23.5-31.6)	**56.8** (48.6-69.4)	**145** (109-198)	**294** (193-385)	1088

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Di-isononyl Phthalate

CAS No. 28553-12-0

General Information

Di-isononyl phthalate (DiNP) is a mixture of phthalates with branched alkyl side chains of varying length (C8, C9, and C10). DiNP is primarily used to produce flexible plastics and has replaced di-2-ethylhexyl phthalate (DEHP) in some plastics, though not in medical products. DiNP is widely used in such products as toys, flooring, gloves, drinking straws, garden hoses, and in sealants used for food packaging. People exposed to DiNP will excrete small amounts of mono-isononyl phthalate (MiNP) and other secondary oxidative metabolites. Urinary MiNP represents only about 2% of a dose (Koch and Angerer, 2007; Silva et al., 2006*a*, 2006*b*). Because DiNP is a complex mixture, MiNP may not reflect exposure to all the chemical components.

DiNP administered to rodents produced liver and kidney toxicity, and may cause liver tumors by a mechanism involving peroxisomal proliferation. High dose DiNP was a developmental toxicant in rodents (NTP-CERHR, 2000). Although DiNP is considered an animal carcinogen, neither IARC nor NTP has evaluated DiNP with respect to human carcinogenicity.

Urinary Mono-isononyl phthalate (MiNP)

Metabolite of Di-isononyl phthalate (DiNP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	**3.50** (<LOD-13.8)	2541
	01-02	*	< LOD	< LOD	< LOD	< LOD	2782
	03-04	*	< LOD	< LOD	< LOD	**1.00** (<LOD-1.30)	2605
Age group							
6-11 years	99-00	*	< LOD	< LOD	< LOD	**6.20** (<LOD-22.5)	328
	01-02	*	< LOD	< LOD	< LOD	< LOD	393
	03-04	*	< LOD	< LOD	**1.00** (<LOD-1.50)	**1.70** (1.20-3.10)	342
12-19 years	99-00	*	< LOD	< LOD	< LOD	**2.30** (<LOD-20.3)	752
	01-02	*	< LOD	< LOD	< LOD	**.900** (<LOD-1.10)	742
	03-04	*	< LOD	< LOD	< LOD	**1.40** (<LOD-1.80)	729
20 years and older	99-00	*	< LOD	< LOD	< LOD	**3.10** (<LOD-13.2)	1461
	01-02	*	< LOD	< LOD	< LOD	< LOD	1647
	03-04	*	< LOD	< LOD	< LOD	< LOD	1534
Gender							
Males	99-00	*	< LOD	< LOD	**.800** (<LOD-5.40)	**4.90** (<LOD-18.9)	1215
	01-02	*	< LOD	< LOD	< LOD	< LOD	1371
	03-04	*	< LOD	< LOD	< LOD	**1.00** (<LOD-1.80)	1250
Females	99-00	*	< LOD	< LOD	< LOD	**2.50** (<LOD-6.80)	1326
	01-02	*	< LOD	< LOD	< LOD	**.900** (<LOD-1.10)	1411
	03-04	*	< LOD	< LOD	< LOD	< LOD	1355
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**1.50** (<LOD-2.80)	814
	01-02	*	< LOD	< LOD	< LOD	**1.00** (<LOD-1.40)	677
	03-04	*	< LOD	< LOD	< LOD	< LOD	652
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**2.30** (<LOD-13.8)	**6.80** (<LOD-30.2)	603
	01-02	*	< LOD	< LOD	< LOD	**1.00** (<LOD-1.70)	703
	03-04	*	< LOD	< LOD	< LOD	**1.30** (1.00-2.00)	699
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	**3.50** (<LOD-16.0)	912
	01-02	*	< LOD	< LOD	< LOD	< LOD	1216
	03-04	*	< LOD	< LOD	< LOD	< LOD	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.8, 0.8, and 1.0, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

MiNP was detected mainly at the 95th percentiles in this *Report*. A low detection rate was also reported in a small sample of African-American women in Washington, DC (Hoppin et al., 2002).

Finding a measurable amount of MiNP in urine does not mean that the levels of MiNP or the parent compound cause an adverse health effect. Biomonitoring studies on levels of MiNP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DiNP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-isononyl phthalate (MiNP) (creatinine corrected)

Metabolite of Di-isononyl phthalate (DiNP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**4.29** (<LOD-8.31)	2541
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	2782
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**2.92** (<LOD-3.18)	2605
Age group							
6-11 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**6.00** (<LOD-14.2)	328
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	393
	03-04	*	**< LOD**	**< LOD**	**2.41** (<LOD-3.13)	**3.27** (2.41-4.67)	342
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**2.00** (<LOD-7.65)	752
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.07** (<LOD-3.33)	742
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**1.97** (<LOD-2.59)	729
20 years and older	99-00	*	**< LOD**	**< LOD**	**< LOD**	**4.62** (<LOD-8.07)	1461
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1647
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1534
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**2.00** (<LOD-3.71)	**4.24** (<LOD-10.2)	1215
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1371
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**2.31** (<LOD-2.95)	1250
Females	99-00	*	**< LOD**	**< LOD**	**< LOD**	**4.29** (<LOD-7.65)	1326
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.73** (<LOD-2.86)	1411
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1355
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**< LOD**	**3.53** (<LOD-5.00)	814
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**2.40** (<LOD-2.73)	677
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	652
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**2.03** (<LOD-5.31)	**4.29** (<LOD-14.3)	603
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**1.76** (<LOD-2.14)	703
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**2.19** (1.67-2.50)	699
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**5.45** (<LOD-10.0)	912
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1216
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1088

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

References

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Dimethyl Phthalate

CAS No.131-11-3

General Information

Dimethyl phthalate (DMP) is used in manufacturing solid rocket propellant and consumer products such as insect repellents and plastics. People exposed to DMP will excrete mono-methyl phthalate (MMP) in their urine. A workplace air standard for external exposure to DMP has been established by OSHA, and guidelines established by ACGIH and NIOSH. Neither IARC nor NTP has evaluated DBP with respect to human carcinogenicity.

Biomonitoring Information

In NHANES 2001-2002 and 2003-2004, the urinary levels of MMP were similar. Among men attending a Boston infertility clinic, at least 75% had detectable urine MMP levels, and the median value was similar to the median urine MMP levels for both males and adults in this *Report* (Hauser et al., 2007). Analysis of the NHANES 2001-2002 levels showed that adjusted geometric mean levels of urinary MMP were higher in children aged 6-11 years than either groups aged 12-19 years or 20 years and older. Females had higher levels than males (CDC, 2005).

Finding a measurable amount of MMP in urine does not mean that the levels of MMP or the parent compound cause an adverse health effect. Biomonitoring studies on levels of urinary MMP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DMP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-methyl phthalate (MMP)

Metabolite of Dimethyl phthalate (DMP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**1.15** (.985-1.34)	**1.50** (1.30-1.80)	**3.30** (2.90-3.70)	**6.00** (5.10-7.50)	**9.80** (8.00-12.5)	2782
	03-04	*	**1.30** (<LOD-1.70)	**3.90** (3.00-4.90)	**9.70** (7.70-12.2)	**16.3** (12.0-20.4)	2605
Age group							
6-11 years	01-02	**1.45** (1.13-1.87)	**1.90** (1.40-2.80)	**4.00** (3.40-4.90)	**7.20** (6.00-8.00)	**11.8** (7.60-20.8)	393
	03-04	**2.10** (1.67-2.63)	**1.70** (1.20-2.40)	**4.30** (2.80-6.40)	**9.50** (6.40-18.8)	**18.8** (9.40-33.4)	342
12-19 years	01-02	**1.59** (1.28-1.96)	**2.10** (1.80-2.50)	**3.90** (3.30-4.70)	**8.50** (5.30-10.5)	**13.0** (9.60-17.8)	742
	03-04	*	**1.50** (1.00-2.20)	**4.40** (3.00-7.00)	**13.3** (7.40-20.9)	**21.8** (17.8-31.5)	729
20 years and older	01-02	**1.06** (.904-1.25)	**1.40** (1.10-1.60)	**3.10** (2.50-3.50)	**5.60** (4.60-7.10)	**9.20** (7.40-12.3)	1647
	03-04	*	**1.20** (<LOD-1.50)	**3.80** (2.80-4.90)	**9.30** (7.10-11.8)	**14.3** (10.8-19.9)	1534
Gender							
Males	01-02	**1.17** (.962-1.43)	**1.50** (1.30-1.90)	**3.30** (2.90-4.00)	**5.90** (4.80-7.90)	**9.20** (7.10-13.5)	1371
	03-04	*	**1.30** (1.00-1.80)	**4.00** (3.20-5.20)	**10.0** (7.30-13.5)	**17.7** (11.8-20.4)	1250
Females	01-02	**1.13** (.973-1.31)	**1.40** (1.10-1.70)	**3.30** (2.80-3.70)	**6.40** (5.00-7.80)	**10.3** (8.20-16.2)	1411
	03-04	*	**1.20** (<LOD-1.60)	**3.60** (2.80-4.70)	**9.50** (7.70-12.2)	**15.3** (11.7-22.9)	1355
Race/ethnicity							
Mexican Americans	01-02	**1.21** (1.02-1.45)	**1.60** (1.30-1.70)	**3.30** (2.70-4.00)	**5.60** (4.70-7.30)	**8.60** (6.40-15.2)	677
	03-04	*	**1.40** (1.10-1.80)	**4.00** (2.50-6.30)	**9.60** (7.30-13.4)	**15.0** (11.4-18.8)	652
Non-Hispanic blacks	01-02	**1.64** (1.37-1.98)	**2.10** (1.70-2.70)	**4.40** (3.60-5.10)	**8.30** (6.20-10.1)	**11.0** (9.50-13.4)	703
	03-04	**2.16** (1.64-2.84)	**1.70** (1.00-2.80)	**5.10** (3.70-7.00)	**11.4** (7.30-17.3)	**17.8** (10.2-39.4)	699
Non-Hispanic whites	01-02	**1.08** (.906-1.29)	**1.40** (1.10-1.70)	**3.20** (2.50-3.60)	**5.60** (4.70-6.70)	**9.70** (7.10-14.0)	1216
	03-04	*	**1.20** (<LOD-1.60)	**3.60** (2.80-4.80)	**9.70** (7.50-12.2)	**16.5** (12.0-20.4)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.2 and 1.0.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Mono-methyl phthalate (MMP) (creatinine corrected)

Metabolite of Dimethyl phthalate (DMP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**1.08** (.936-1.25)	**1.33** (1.13-1.55)	**2.62** (2.36-2.97)	**5.00** (3.97-6.02)	**8.00** (6.07-11.0)	2782
	03-04	*	**1.53** (<LOD-1.79)	**3.45** (2.76-4.37)	**7.95** (5.83-11.8)	**13.5** (11.3-18.1)	2605
Age group							
6-11 years	01-02	**1.65** (1.28-2.14)	**2.32** (1.72-2.86)	**3.97** (3.27-4.71)	**7.20** (5.99-9.41)	**13.2** (7.60-22.5)	393
	03-04	**2.22** (1.75-2.81)	**1.88** (1.49-2.60)	**4.96** (2.81-6.49)	**9.67** (6.15-14.6)	**16.2** (12.1-34.5)	342
12-19 years	01-02	**1.23** (1.01-1.48)	**1.51** (1.32-1.82)	**2.84** (2.52-3.33)	**5.36** (3.68-6.39)	**7.27** (5.64-11.4)	742
	03-04	*	**1.34** (1.12-1.73)	**3.19** (2.26-4.43)	**7.84** (4.95-12.1)	**13.3** (9.49-19.1)	729
20 years and older	01-02	**1.00** (.868-1.16)	**1.21** (1.05-1.40)	**2.44** (2.14-2.68)	**4.53** (3.49-6.02)	**7.72** (5.52-11.4)	1647
	03-04	*	**1.52** (<LOD-1.79)	**3.39** (2.69-4.31)	**7.69** (5.40-11.8)	**13.3** (10.1-18.9)	1534
Gender							
Males	01-02	**.954** (.794-1.15)	**1.17** (1.02-1.40)	**2.37** (2.03-2.75)	**4.18** (3.45-5.64)	**6.42** (4.94-9.59)	1371
	03-04	*	**1.35** (1.15-1.52)	**2.95** (2.26-4.09)	**7.11** (5.00-10.2)	**11.8** (9.05-13.3)	1250
Females	01-02	**1.21** (1.06-1.38)	**1.45** (1.23-1.82)	**2.87** (2.58-3.06)	**5.56** (4.55-7.14)	**10.0** (7.20-15.3)	1411
	03-04	*	**1.83** (<LOD-2.10)	**3.87** (3.04-4.96)	**9.41** (6.41-13.6)	**16.5** (12.5-23.5)	1355
Race/ethnicity							
Mexican Americans	01-02	**1.14** (.975-1.34)	**1.48** (1.30-1.63)	**2.50** (2.20-2.94)	**4.19** (3.77-5.76)	**8.47** (5.58-12.5)	677
	03-04	*	**1.36** (1.15-1.71)	**3.56** (2.45-4.90)	**7.53** (5.62-9.64)	**12.5** (9.44-16.9)	652
Non-Hispanic blacks	01-02	**1.15** (.949-1.40)	**1.39** (1.29-1.67)	**2.70** (2.36-2.95)	**4.87** (4.21-5.93)	**8.09** (5.86-11.0)	703
	03-04	**1.53** (1.21-1.94)	**1.40** (1.07-1.75)	**3.14** (2.26-4.37)	**7.50** (4.29-14.6)	**13.7** (7.70-20.7)	699
Non-Hispanic whites	01-02	**1.07** (.914-1.26)	**1.30** (1.05-1.58)	**2.62** (2.32-2.99)	**5.22** (3.68-6.82)	**8.26** (6.07-12.6)	1216
	03-04	*	**1.56** (<LOD-1.89)	**3.50** (2.71-4.67)	**8.10** (6.00-11.9)	**13.6** (11.3-18.9)	1088

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

References

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Hauser R, Meeker JD, Singh NP, Silva MJ, Ryan L, Duty S, et al. DNA damage in human sperm is related to urinary levels of phthalate monoester and oxidative metabolites. Hum Reprod 2007;22(3):688-695.

Di-n-octyl Phthalate

CAS No. 117-84-0

General Information

Di-n-octyl phthalate (DOP) is added to polyvinyl chloride resins used in diverse products including floorings, carpet tiles, vinyl gloves, garden hoses, wire and cable insulation, and adhesives. In addition, DOP may be added to polyvinyl chloride with food applications, such as package sealants and bottle cap liners. People exposed to DOP will excrete primarily mono-3-carboxypropyl phthalate (MCPP) and smaller amounts of mono-n-octyl phthalate (MOP) and other oxidative metabolites in their urine. In rodent studies, oral DOP produces liver and thyroid toxicity (NTP-CERHR, 2000). Neither IARC nor NTP has evaluated DOP with respect to human carcinogenicity.

Biomonitoring Information

In NHANES 1999-2000, MOP was only detectable at the 90th and 95th percentiles, and less frequently detected in the 2001-2002 and 2003-2004 survey periods. A low detection rate was reported in small samples of German residents (Koch et al., 2003) and of African-American women in Washington, DC (Hoppin et al., 2002). MCPP levels measured in NHANES 2001-2002 and 2003-2004 subsamples had overall median values that were roughly similar to a smaller sample of U.S. adults (Calafat et al., 2006).

Finding a measurable amount of MCPP or MOP in urine does not mean that the levels of MCPP or MOP or the parent compound cause an adverse health effect. Biomonitoring studies on levels of MCPP and MOP provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of DOP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Mono-(3-carboxypropyl) phthalate (MCPP)

Metabolite of Di-n-octyl phthalate (DOP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2.75** (2.49-3.04)	**3.10** (2.80-3.30)	**5.70** (5.10-6.40)	**10.0** (8.90-11.3)	**14.6** (12.7-17.5)	2782
	03-04	**2.91** (2.79-3.04)	**3.10** (3.00-3.30)	**5.70** (5.20-6.10)	**10.2** (9.20-11.8)	**15.3** (13.8-16.2)	2605
Age group							
6-11 years	01-02	**6.11** (5.46-6.84)	**6.70** (5.40-7.50)	**11.8** (10.2-13.3)	**20.1** (17.8-23.1)	**24.7** (22.2-31.6)	393
	03-04	**6.86** (5.80-8.11)	**7.10** (6.00-8.90)	**12.7** (10.4-16.4)	**22.0** (17.2-27.7)	**29.2** (22.3-36.6)	342
12-19 years	01-02	**3.71** (3.18-4.33)	**4.00** (3.40-4.70)	**7.10** (6.10-8.10)	**11.5** (9.50-12.7)	**14.1** (11.8-19.0)	742
	03-04	**3.72** (3.33-4.15)	**4.10** (3.50-4.60)	**7.20** (5.80-8.40)	**11.0** (9.50-13.6)	**15.4** (13.4-17.9)	729
20 years and older	01-02	**2.37** (2.11-2.66)	**2.60** (2.20-3.00)	**4.80** (4.30-5.40)	**8.10** (7.20-9.50)	**12.0** (10.1-14.2)	1647
	03-04	**2.53** (2.41-2.66)	**2.80** (2.60-2.90)	**4.90** (4.50-5.20)	**8.10** (7.50-8.90)	**13.2** (10.8-14.3)	1534
Gender							
Males	01-02	**2.89** (2.64-3.17)	**3.10** (2.80-3.40)	**5.70** (5.00-6.80)	**9.90** (8.70-12.0)	**14.2** (12.4-18.1)	1371
	03-04	**3.25** (3.01-3.52)	**3.30** (3.00-3.60)	**6.00** (5.60-6.80)	**11.8** (10.1-13.6)	**16.0** (14.2-20.0)	1250
Females	01-02	**2.62** (2.29-2.99)	**3.00** (2.50-3.30)	**5.70** (5.00-6.30)	**10.0** (8.50-11.5)	**14.7** (11.2-20.3)	1411
	03-04	**2.63** (2.44-2.83)	**3.00** (2.60-3.20)	**5.20** (4.70-5.80)	**9.20** (8.20-10.3)	**13.4** (11.0-16.2)	1355
Race/ethnicity							
Mexican Americans	01-02	**2.67** (2.26-3.16)	**3.00** (2.30-3.50)	**5.30** (4.40-5.90)	**9.20** (7.30-12.4)	**13.6** (10.4-18.7)	677
	03-04	**3.08** (2.86-3.32)	**3.10** (2.80-3.40)	**5.50** (4.80-6.10)	**9.90** (7.90-12.6)	**13.7** (11.5-19.8)	652
Non-Hispanic blacks	01-02	**3.09** (2.81-3.40)	**3.30** (2.90-3.60)	**6.30** (5.50-6.50)	**10.9** (9.10-13.0)	**15.1** (13.5-22.4)	703
	03-04	**3.30** (3.01-3.62)	**3.20** (2.90-3.60)	**6.10** (5.50-6.90)	**11.6** (9.30-13.4)	**20.1** (13.6-25.5)	699
Non-Hispanic whites	01-02	**2.72** (2.40-3.08)	**3.00** (2.60-3.30)	**5.80** (4.80-6.80)	**10.3** (8.90-11.9)	**15.8** (12.6-19.5)	1216
	03-04	**2.87** (2.73-3.02)	**3.10** (2.90-3.30)	**5.60** (5.00-6.00)	**10.1** (9.10-12.0)	**15.2** (13.4-16.1)	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.4 and 0.2.

Urinary Mono-(3-carboxypropyl) phthalate (MCPP) (creatinine corrected)

Metabolite of Di-n-octyl phthalate (DOP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2.58** (2.35-2.83)	**2.47** (2.25-2.76)	**4.08** (3.87-4.48)	**7.24** (6.58-8.00)	**11.4** (10.0-12.5)	2782
	03-04	**2.74** (2.56-2.93)	**2.60** (2.42-2.79)	**4.39** (3.94-4.86)	**7.70** (6.65-8.60)	**10.7** (9.53-11.9)	2605
Age group							
6-11 years	01-02	**6.96** (6.29-7.70)	**7.08** (5.83-7.87)	**11.2** (9.15-14.0)	**20.7** (15.5-22.3)	**26.4** (20.7-27.0)	393
	03-04	**7.25** (6.43-8.18)	**7.06** (5.93-7.59)	**11.2** (9.38-12.4)	**19.1** (14.4-25.6)	**26.9** (19.3-29.0)	342
12-19 years	01-02	**2.86** (2.52-3.25)	**2.94** (2.50-3.36)	**4.59** (4.03-5.23)	**6.69** (6.30-7.25)	**9.55** (8.03-10.7)	742
	03-04	**2.78** (2.54-3.05)	**2.75** (2.53-2.99)	**4.55** (4.05-5.15)	**6.61** (6.15-7.20)	**8.24** (7.00-10.2)	729
20 years and older	01-02	**2.24** (2.03-2.47)	**2.20** (2.00-2.40)	**3.51** (3.11-3.95)	**5.39** (4.82-6.18)	**7.71** (6.71-9.28)	1647
	03-04	**2.43** (2.27-2.61)	**2.38** (2.19-2.56)	**3.70** (3.33-4.08)	**6.09** (5.38-7.06)	**8.79** (7.84-9.56)	1534
Gender							
Males	01-02	**2.35** (2.17-2.56)	**2.20** (2.02-2.42)	**3.76** (3.45-4.20)	**7.17** (6.27-8.06)	**11.5** (9.28-15.1)	1371
	03-04	**2.55** (2.39-2.72)	**2.36** (2.22-2.47)	**4.14** (3.52-4.86)	**7.84** (6.80-8.79)	**11.6** (10.2-13.5)	1250
Females	01-02	**2.81** (2.48-3.18)	**2.76** (2.46-3.02)	**4.39** (3.97-4.92)	**7.66** (6.17-8.69)	**11.0** (8.62-15.9)	1411
	03-04	**2.93** (2.68-3.20)	**2.89** (2.58-3.23)	**4.53** (4.09-5.00)	**7.58** (6.44-8.57)	**10.0** (8.60-11.6)	1355
Race/ethnicity							
Mexican Americans	01-02	**2.52** (2.21-2.88)	**2.37** (2.07-2.73)	**4.29** (3.73-5.00)	**7.36** (5.58-10.3)	**11.4** (8.36-14.5)	677
	03-04	**2.78** (2.56-3.02)	**2.63** (2.30-2.96)	**4.32** (3.66-4.96)	**8.14** (6.72-10.3)	**12.8** (9.37-17.1)	652
Non-Hispanic blacks	01-02	**2.17** (2.02-2.33)	**2.07** (1.88-2.28)	**3.68** (3.25-4.07)	**6.73** (5.46-7.70)	**10.0** (8.27-13.1)	703
	03-04	**2.34** (2.13-2.58)	**2.17** (1.99-2.45)	**3.96** (3.33-4.43)	**6.93** (6.03-8.80)	**13.4** (9.32-15.9)	699
Non-Hispanic whites	01-02	**2.69** (2.42-3.00)	**2.57** (2.25-2.94)	**4.19** (3.87-4.79)	**7.63** (6.58-8.45)	**11.8** (10.0-14.7)	1216
	03-04	**2.83** (2.60-3.09)	**2.65** (2.43-2.96)	**4.55** (3.90-5.16)	**7.79** (6.59-8.79)	**10.6** (9.43-11.3)	1088

Urinary Mono-n-octyl phthalate (MOP)

Metabolite of Di-n-octyl phthalate (DOP)

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**1.60** (1.20-2.00)	**2.90** (2.30-3.40)	2541
	01-02	*	< LOD	< LOD	< LOD	< LOD	2782
	03-04	*	< LOD	< LOD	< LOD	< LOD	2605
Age group							
6-11 years	99-00	*	< LOD	< LOD	**2.20** (.900-3.50)	**3.20** (1.70-5.00)	328
	01-02	*	< LOD	< LOD	< LOD	< LOD	393
	03-04	*	< LOD	< LOD	< LOD	< LOD	342
12-19 years	99-00	*	< LOD	< LOD	**1.70** (.900-2.50)	**2.80** (2.00-4.20)	752
	01-02	*	< LOD	< LOD	< LOD	< LOD	742
	03-04	*	< LOD	< LOD	< LOD	< LOD	729
20 years and older	99-00	*	< LOD	< LOD	**1.50** (1.10-1.90)	**2.90** (2.10-3.50)	1461
	01-02	*	< LOD	< LOD	< LOD	< LOD	1647
	03-04	*	< LOD	< LOD	< LOD	< LOD	1534
Gender							
Males	99-00	*	< LOD	< LOD	**1.60** (1.10-2.20)	**2.80** (2.00-3.50)	1215
	01-02	*	< LOD	< LOD	< LOD	< LOD	1371
	03-04	*	< LOD	< LOD	< LOD	< LOD	1250
Females	99-00	*	< LOD	< LOD	**1.50** (1.20-2.10)	**3.10** (2.20-3.80)	1326
	01-02	*	< LOD	< LOD	< LOD	< LOD	1411
	03-04	*	< LOD	< LOD	< LOD	< LOD	1355
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**1.10** (<LOD-1.40)	**1.60** (1.40-2.60)	814
	01-02	*	< LOD	< LOD	< LOD	< LOD	677
	03-04	*	< LOD	< LOD	< LOD	< LOD	652
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**1.90** (<LOD-3.00)	**3.00** (2.20-4.10)	603
	01-02	*	< LOD	< LOD	< LOD	< LOD	703
	03-04	*	< LOD	< LOD	< LOD	< LOD	699
Non-Hispanic whites	99-00	*	< LOD	< LOD	**1.60** (1.20-2.10)	**3.00** (2.30-3.50)	912
	01-02	*	< LOD	< LOD	< LOD	< LOD	1216
	03-04	*	< LOD	< LOD	< LOD	< LOD	1088

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.9, 1.0, and 1.0, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Urinary Mono-n-octyl phthalate (MOP) (creatinine corrected)

Metabolite of Di-n-octyl phthalate (DOP)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**2.40** (2.07-2.61)	**3.53** (2.95-4.29)	2541
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	2782
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	2605
Age group							
6-11 years	99-00	*	**< LOD**	**< LOD**	**2.22** (1.60-3.75)	**3.75** (1.97-10.3)	328
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	393
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	342
12-19 years	99-00	*	**< LOD**	**< LOD**	**1.49** (1.29-1.71)	**1.88** (1.54-3.33)	752
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	742
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	729
20 years and older	99-00	*	**< LOD**	**< LOD**	**2.60** (2.07-2.91)	**3.53** (3.00-4.62)	1461
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1647
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1534
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**1.82** (1.54-2.07)	**2.56** (1.94-3.45)	1215
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1371
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1250
Females	99-00	*	**< LOD**	**< LOD**	**3.00** (2.50-3.55)	**4.29** (3.33-6.23)	1326
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1411
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1355
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**1.82** (<LOD-2.80)	**3.33** (2.60-4.00)	814
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	677
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	652
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**1.36** (<LOD-1.94)	**2.22** (1.50-3.27)	603
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	703
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	699
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**2.61** (2.14-3.08)	**3.64** (3.15-5.00)	912
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1216
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1088

< LOD means less than the limit of detection for the urine levels not corrected for creatinine.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Phytoestrogens

General Informatgraceion

Phytoestrogens are naturally occurring polycyclic phenols found in certain plants. These are chemicals that may have weak estrogenic effects when they are ingested and metabolized. Two important groups of phytoestrogens are isoflavones and lignans. The table shows the phytoestrogen classes, examples, and some human urinary metabolites.

The isoflavones considered here include formononetin, daidzein, biochanin A, genistein, O-desmethylangolensin, and equol. Plant sources of isoflavones include legumes, with the largest contribution coming from soy-based foods. Because soy flour and soy protein isolates may be added to processed meats, meat substitutes, breads, and protein food bars, these items can be a major source of isoflavones (Grace et al., 2004; Lampe et al., 1999). However, the isoflavone content of soy protein preparations can vary widely and is affected by production techniques (Erdman et al., 2004). Daidzein and genistein are the main soy isoflavones. Kudzu root, used in some dietary supplements, also contains appreciable amounts of daidzein. Naringenin, a precursor to genistein, is found in some citrus fruits. Formononetin and biochanin A are methylated isoflavones found in clovers, which may be used in red clover dietary supplements; these isoflavones are metabolized in the body to daidzein and genistein, respectively.

Ingested daidzein is further metabolized to O-desmethylangolensin and to equol by intestinal bacteria. Equol, but not O-desmethylangolensin, has estrogenic activity. About 30% of adults can be characterized as equol producers and demonstrate higher serum equol levels after daidzein consumption (Cassidy et al., 2006; Setchell et al., 2003). This ability to produce equol may be related to an individual's intestinal microflora and influenced by dietary habits (Rowland et al., 2000). The relevance of equol-producer status to potential health related effects is unclear (Vafeiadou et al., 2006).

Lignans include matairesinol and secoisolariciresinol, which are transformed by intestinal bacteria into the estrogenic compounds enterolactone and enterodiol, respectively (Cornwell et al., 2004; Rowland et al., 2003). Enterodiol may also interconvert with enterolactone. Lignans are found in flax seeds, whole wheat flour, tea, some fruits, and other cereal grains. Other phytoestrogens of interest are resveratrol and trans-resveratrol, found in grape skins, wine, and peanuts.

Diet is the source of human exposure to phytoestrogens. The absorption and metabolism of phytoestrogens demonstrate large interindividual variability, which may relate to differences in both human pharmacokinetics and metabolism by intestinal bacteria. Phytoestrogens are ingested in their naturally occurring beta-glycosidic forms. The beta-glycosidic forms are hydrolyzed to their aglycones in the intestine, absorbed, and then glucuronidated in the intestinal wall and liver (Doerge et al., 2000; Rowland et al., 2003). The glucuronidated metabolites of isoflavones predominate in blood and urine (Rozman et al., 2006*a;* Setchell et al., 2001).

The isoflavones are excreted from the body about 24 hours after ingestion, mainly in urine and, to a lesser extent, in feces. Urinary concentrations of daidzein and genistein did not correlate well with the ingested doses, possibly due to limited absorption of these isoflavones at higher doses (Setchell et al., 2003*a*). In contrast, plasma and urine lignan concentrations after flax seed consumption increased in a dose-dependent manner (Nesbitt et al., 1999). Equol excretion may depend on diet, the type of intestinal bacteria present, and individual genetic factors (Rowland et al., 2000; Setchell et al., 2002; Setchell and Cassidy, 1999).

Phytoestrogens and Urinary Metabolites in this *Report*

Phytoestrogen Class	**Phytoestrogen or Metabolite** (CAS number)
Isoflavones	Daidzein (486-66-8) O-Desmethylangolensin (21255-69-6) Equol (531-95-3) Genistein (466-72-0)
Lignans	Enterolactone (78473-71-9) Enterodiol (80226-00-2)

After hydrolysis to the aglycone forms, phytoestrogens can weakly bind to estrogen-beta receptors (ER-beta) which are expressed in arteries and smooth muscle. Individual phytoestrogens may be either estrogen agonists or antagonists. Equol has more potent estrogenic activity than its precursor, daidzein. Equol also has been shown to have antiandrogenic activity in animals (Lund et al., 2004; Magee and Rowland, 2004). Genistein binds ER-beta with greater affinity than equol (Doerge and Sheehan, 2002). Although far less potent, phytoestrogens can be present in concentrations 100 to 1000 times greater than the endogenously produced estrogens. Soy-based infant formula can result in plasma concentrations of isoflavones in infants that are 13,000-22,000 times higher than endogenous estrogen concentrations in infants (Setchell et al., 1997). Phytoestrogens may also act through pathways other than the interaction with estrogen receptors. These actions include inhibiting the transformation of estrone to estradiol, inhibiting enzymes important for steroid biosynthesis and cell growth, and having antioxidant and anti-angiogenesis activities. (Adlercreutz et al., 1995*a*; Dixon and Ferreira, 2002; Sirtori et al., 2005). Numerous studies of either dietary soy or phytoestrogens and health outcomes have demonstrated inconsistent or inconclusive results. Consensus reviews of these studies suggest that no evidence clearly shows that dietary phytoestrogens significantly reduce cardiovascular disease risk, reduce postmenopausal vasomotor symptoms, improve bone

Urinary Daidzein

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**75.1** (61.9-91.1)	**69.8** (57.8-82.6)	**229** (184-298)	**538** (471-702)	**1320** (1020-1540)	2553
	01-02	**51.7** (46.6-57.5)	**52.3** (48.9-57.4)	**192** (151-226)	**577** (447-725)	**1250** (863-1640)	2794
	03-04	**66.7** (60.4-73.7)	**62.0** (54.1-69.7)	**195** (171-219)	**590** (500-675)	**1070** (893-1330)	2594
Age group							
6-11 years	99-00	**90.5** (75.1-109)	**101** (70.3-138)	**257** (172-430)	**510** (437-840)	**1130** (657-1740)	330
	01-02	**84.9** (71.6-101)	**72.7** (56.3-97.0)	**261** (155-385)	**605** (437-989)	**1060** (645-1500)	396
	03-04	**84.9** (71.6-101)	**66.8** (55.4-92.8)	**229** (151-314)	**574** (371-654)	**818** (625-1060)	341
12-19 years	99-00	**123** (91.4-166)	**124** (85.6-168)	**326** (227-454)	**833** (445-1490)	**1460** (861-2410)	753
	01-02	**69.3** (52.6-91.3)	**70.2** (52.5-87.5)	**255** (185-344)	**774** (573-984)	**1360** (922-1950)	744
	03-04	**89.0** (75.2-105)	**78.0** (59.0-104)	**248** (197-332)	**808** (500-968)	**1200** (900-1790)	729
20 years and older	99-00	**67.6** (55.4-82.4)	**60.9** (49.3-74.1)	**215** (167-239)	**518** (459-573)	**1320** (978-1540)	1470
	01-02	**46.4** (41.4-52.0)	**49.1** (40.8-53.4)	**176** (133-216)	**520** (396-703)	**1210** (771-1900)	1654
	03-04	**61.9** (55.2-69.4)	**57.9** (48.7-68.5)	**180** (150-214)	**554** (416-695)	**1110** (857-1360)	1524
Gender							
Males	99-00	**88.9** (71.4-111)	**80.6** (66.6-112)	**262** (198-355)	**587** (501-989)	**1540** (989-2080)	1220
	01-02	**49.8** (42.8-57.9)	**50.8** (46.0-55.0)	**190** (137-240)	**498** (386-694)	**920** (717-1380)	1375
	03-04	**73.8** (63.4-85.9)	**65.2** (56.1-76.4)	**214** (156-311)	**709** (535-900)	**1200** (969-1380)	1244
Females	99-00	**64.1** (52.9-77.6)	**57.8** (45.0-73.2)	**199** (150-244)	**476** (389-722)	**1220** (566-1700)	1333
	01-02	**53.6** (48.1-59.8)	**55.7** (49.8-62.7)	**199** (149-234)	**642** (511-816)	**1470** (1170-1980)	1419
	03-04	**60.7** (53.6-68.8)	**57.4** (49.1-67.6)	**175** (159-201)	**466** (381-622)	**884** (654-1380)	1350
Race/ethnicity							
Mexican Americans	99-00	**78.9** (59.8-104)	**66.2** (48.4-87.1)	**254** (170-402)	**806** (534-1020)	**1360** (968-2780)	816
	01-02	**39.2** (28.5-54.0)	**39.9** (28.8-59.9)	**169** (100-291)	**515** (388-669)	**896** (613-1480)	679
	03-04	**57.4** (50.2-65.7)	**45.5** (35.2-53.3)	**178** (130-236)	**686** (487-934)	**1390** (934-1650)	653
Non-Hispanic blacks	99-00	**91.9** (71.9-118)	**103** (81.6-133)	**286** (243-377)	**553** (459-824)	**1190** (640-1900)	607
	01-02	**66.1** (48.2-90.7)	**72.9** (52.8-97.3)	**255** (182-393)	**757** (448-1400)	**1410** (757-2480)	706
	03-04	**75.0** (56.1-100)	**66.0** (50.7-86.6)	**241** (151-340)	**622** (408-875)	**1190** (660-2300)	699
Non-Hispanic whites	99-00	**74.4** (61.5-89.9)	**66.9** (56.2-78.2)	**216** (157-298)	**512** (438-745)	**1360** (989-1710)	917
	01-02	**48.6** (43.8-54.0)	**49.8** (42.8-54.2)	**171** (137-204)	**504** (389-658)	**1140** (774-1620)	1222
	03-04	**65.8** (58.6-74.0)	**62.0** (52.8-71.9)	**191** (165-215)	**572** (416-722)	**1070** (823-1330)	1079

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.5, 1.6, and 1.6, respectively.

mineral density, or reduce cancer risk (Cornwell et al., 2004; Messina et al., 2006; NAMS, 2000; Nedrow et al., 2006; Sacks et al., 2006; Sirtori et al., 2005).

Adverse effects on fertility have been observed in animals that graze on red clover. Results of chronic feeding studies in pregnant animals suggest that high doses of phytoestrogens alter the fetal hormonal environment (Cornwell et al., 2004). Studies of children who had been fed soy-based formula as infants and who were followed through adolescence (Klein, 1998) and young adulthood (Strom et al., 2001) found no adverse reproductive or endocrine effects. *In vitro* and animal studies suggest that soy isoflavones may have immunologic and thyroid effects (Doerge and Sheehan, 2002; Sirtori et al., 2005). The Center for the Evaluation of Risks to Human Reproduction (CERHR) of the National Toxicology Program reviewed developmental and reproductive toxicity of both soy formula and genistein and concluded that available data were inadequate to determine whether soy formula has developmental or reproductive toxicity (Rozman et al., 2006*a*). The expert review panel expressed negligible concern for adverse effects in the general population consuming dietary sources of genistein (Rozman et al., 2006*b*).

Biomonitoring Information

The concentrations of urinary phytoestrogens observed

Urinary Daidzein (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**68.5** (55.9-83.9)	**65.1** (52.8-80.8)	**204** (156-249)	**560** (471-629)	**944** (836-1150)	2553
	01-02	**48.5** (43.7-54.0)	**48.3** (43.1-56.5)	**166** (140-196)	**500** (391-608)	**957** (801-1180)	2794
	03-04	**62.5** (58.3-67.0)	**56.1** (50.0-63.6)	**164** (144-187)	**502** (429-591)	**1060** (825-1150)	2594
Age group							
6-11 years	99-00	**92.6** (76.3-112)	**93.1** (71.2-114)	**251** (157-324)	**552** (363-838)	**1070** (781-2150)	330
	01-02	**96.4** (79.0-118)	**85.9** (60.3-127)	**275** (159-395)	**655** (452-733)	**938** (683-1140)	396
	03-04	**90.4** (77.2-106)	**72.8** (58.2-99.5)	**201** (152-240)	**454** (329-638)	**702** (526-1200)	341
12-19 years	99-00	**83.1** (58.4-118)	**85.6** (53.8-126)	**207** (138-386)	**628** (295-1060)	**1000** (628-2380)	753
	01-02	**53.4** (40.8-70.0)	**50.9** (38.3-77.6)	**181** (142-248)	**549** (385-718)	**1030** (622-1360)	744
	03-04	**66.6** (55.7-79.6)	**56.4** (43.9-74.6)	**179** (151-217)	**517** (370-753)	**877** (617-1240)	729
20 years and older	99-00	**63.8** (51.5-79.1)	**59.3** (48.7-75.0)	**194** (151-234)	**554** (471-624)	**908** (783-1180)	1470
	01-02	**43.9** (39.4-48.9)	**43.8** (37.4-53.3)	**153** (125-186)	**428** (348-590)	**946** (728-1220)	1654
	03-04	**59.2** (54.3-64.5)	**51.7** (46.4-62.6)	**155** (131-185)	**501** (404-658)	**1090** (808-1240)	1524
Gender							
Males	99-00	**69.7** (54.7-88.8)	**70.2** (51.3-84.3)	**198** (147-276)	**623** (494-836)	**1050** (884-1290)	1220
	01-02	**40.5** (34.8-47.1)	**41.7** (34.5-47.9)	**139** (107-179)	**348** (260-553)	**788** (585-947)	1375
	03-04	**57.7** (49.4-67.3)	**48.9** (41.6-58.3)	**160** (126-205)	**467** (368-600)	**919** (665-1200)	1244
Females	99-00	**67.4** (54.8-82.9)	**62.6** (51.1-80.9)	**207** (152-250)	**509** (356-624)	**850** (610-1410)	1333
	01-02	**57.6** (50.8-65.2)	**59.5** (48.1-73.4)	**191** (159-227)	**615** (536-722)	**1180** (924-1430)	1419
	03-04	**67.4** (60.8-74.9)	**65.1** (54.6-73.4)	**165** (143-191)	**564** (409-699)	**1090** (757-1370)	1350
Race/ethnicity							
Mexican Americans	99-00	**72.5** (59.1-88.9)	**64.2** (47.1-91.1)	**243** (176-310)	**677** (468-1080)	**1380** (753-2690)	816
	01-02	**36.9** (27.8-49.0)	**37.1** (24.8-57.9)	**146** (101-225)	**441** (307-596)	**722** (565-1160)	679
	03-04	**51.8** (45.0-59.6)	**47.7** (35.9-58.3)	**159** (117-209)	**502** (354-686)	**1130** (779-1390)	653
Non-Hispanic blacks	99-00	**59.1** (46.5-75.1)	**67.6** (52.1-87.1)	**172** (134-207)	**381** (316-533)	**802** (562-1010)	607
	01-02	**46.4** (33.7-63.8)	**49.8** (35.5-69.7)	**169** (104-249)	**504** (263-773)	**939** (542-1530)	706
	03-04	**53.1** (42.5-66.4)	**44.7** (28.6-72.1)	**147** (121-191)	**415** (275-538)	**727** (538-1040)	699
Non-Hispanic whites	99-00	**72.8** (60.3-88.0)	**67.5** (55.3-81.5)	**207** (160-249)	**560** (442-659)	**908** (742-1350)	917
	01-02	**48.1** (43.4-53.3)	**47.0** (42.1-56.0)	**163** (137-191)	**463** (375-627)	**957** (805-1220)	1222
	03-04	**64.9** (59.8-70.3)	**58.2** (50.4-66.3)	**165** (138-204)	**516** (385-667)	**1090** (786-1250)	1079

in the NHANES 1999-2000, 2000-2001, and 2003-2004 subsamples generally reflect a diet consumed in the U.S. that is lower in isoflavones than in lignans. This is consistent with a Western diet in which whole grains and cereals, rather than soybean products, contribute the bulk of phytoestrogens (CDC, 2005). Enterolactone levels were highest, followed by daidzein, enterodiol, genistein, equol, and O-desmethylangolensin. Isoflavone levels at the higher percentiles may reflect dietary supplementation with soy products. The relationship between the dose and urinary excretion is linear for many phytoestrogens, except for equol (Karr et al., 1997; Slavin et al., 1998). Because excretory half-lives are reported to be in the range of 3-10 hours (Lu et al., 1995; Setchell et al., 2001), urinary concentrations reflect recent consumption.

Levels of lignans (enterolactone, enterodiol) in the NHANES 1999-2000, 2001-2002, and 2003-2004 subsamples appeared broadly similar to levels found in studies of postmenopausal women in the United Kingdom (Grace et al., 2004); men and women in the U. S. (Valentin-Blasini et al., 2003); men and women in Minnesota (Lampe et al., 1999); postmenopausal Dutch women (den Tonkelaar et al., 2001); young African-American, Latina, and Japanese women in the San Francisco Bay Area (Horn-Ross et al., 1997); Japanese men and women (Adlercreutz et al., 1991; Uehara et al., 2000*a*); premenopausal omnivorous women in Boston (Adlercreutz et al., 1986); and healthy

Urinary O-Desmethylangolensin

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**4.39** (3.37-5.73)	**4.98** (3.65-6.77)	**22.7** (18.7-30.1)	**100** (74.8-141)	**222** (182-250)	2271
	01-02	**4.08** (3.53-4.73)	**3.30** (2.70-4.20)	**19.8** (16.7-24.6)	**96.0** (70.1-135)	**260** (161-437)	2794
	03-04	**4.91** (4.34-5.55)	**4.60** (4.00-5.20)	**23.6** (18.6-27.2)	**95.9** (70.7-122)	**230** (185-342)	2581
Age group							
6-11 years	99-00	**5.60** (3.85-8.15)	**7.52** (3.43-15.2)	**36.2** (20.3-45.0)	**78.7** (43.4-191)	**176** (74.8-264)	287
	01-02	**6.19** (4.51-8.49)	**5.90** (3.80-9.30)	**26.9** (15.7-52.1)	**122** (61.5-215)	**281** (161-466)	396
	03-04	**6.33** (4.30-9.30)	**6.10** (3.50-10.6)	**24.0** (17.0-33.8)	**70.8** (51.4-122)	**138** (80.9-256)	341
12-19 years	99-00	**6.04** (3.76-9.70)	**7.60** (5.13-13.5)	**36.6** (22.0-57.3)	**107** (63.4-165)	**194** (107-238)	667
	01-02	**5.92** (4.46-7.87)	**5.20** (3.70-7.60)	**33.6** (18.0-56.8)	**125** (91.2-172)	**299** (172-435)	744
	03-04	**6.37** (4.95-8.18)	**5.30** (3.80-8.10)	**33.9** (18.2-50.5)	**110** (82.2-198)	**257** (175-415)	729
20 years and older	99-00	**4.05** (3.12-5.26)	**4.46** (3.31-5.64)	**19.8** (16.0-26.5)	**101** (80.8-150)	**228** (179-259)	1317
	01-02	**3.65** (3.08-4.32)	**2.80** (2.30-3.70)	**17.0** (13.9-22.4)	**81.5** (63.0-128)	**260** (135-526)	1654
	03-04	**4.56** (4.02-5.17)	**4.40** (3.60-4.90)	**22.0** (17.8-25.6)	**94.0** (67.6-131)	**230** (187-398)	1511
Gender							
Males	99-00	**4.97** (3.71-6.66)	**5.62** (4.12-8.73)	**29.1** (19.8-42.9)	**121** (74.1-190)	**235** (177-332)	1087
	01-02	**3.81** (3.08-4.71)	**3.30** (2.60-4.50)	**17.4** (13.2-24.6)	**82.8** (58.4-116)	**194** (123-324)	1375
	03-04	**4.90** (3.93-6.12)	**4.60** (3.40-5.50)	**23.0** (16.6-30.1)	**92.9** (70.7-129)	**222** (159-332)	1240
Females	99-00	**3.92** (2.97-5.16)	**4.22** (3.18-5.51)	**19.4** (14.1-26.1)	**83.8** (61.1-114)	**192** (123-250)	1184
	01-02	**4.36** (3.64-5.23)	**3.40** (2.50-4.60)	**21.3** (16.8-29.2)	**107** (70.6-199)	**394** (230-746)	1419
	03-04	**4.91** (4.26-5.66)	**4.60** (3.90-5.50)	**23.9** (18.1-27.4)	**99.3** (63.5-155)	**283** (160-433)	1341
Race/ethnicity							
Mexican Americans	99-00	**2.41** (1.55-3.73)	**2.14** (1.31-3.37)	**21.0** (10.6-30.5)	**97.6** (59.7-140)	**191** (122-320)	721
	01-02	**2.44** (1.51-3.94)	**1.40** (.500-3.40)	**13.1** (5.80-27.6)	**66.4** (33.5-102)	**152** (75.8-265)	679
	03-04	**2.54** (1.86-3.48)	**1.90** (1.00-3.40)	**14.4** (9.00-18.1)	**62.3** (40.3-99.5)	**146** (99.5-254)	652
Non-Hispanic blacks	99-00	**5.74** (4.55-7.24)	**8.71** (5.82-10.9)	**33.5** (22.1-52.4)	**108** (78.3-156)	**192** (149-255)	538
	01-02	**5.35** (4.00-7.14)	**5.30** (2.90-7.30)	**32.7** (22.0-52.4)	**128** (75.9-216)	**308** (150-436)	706
	03-04	**5.49** (4.05-7.46)	**4.20** (3.30-6.10)	**26.1** (13.4-49.0)	**117** (86.2-166)	**221** (177-354)	698
Non-Hispanic whites	99-00	**4.50** (3.26-6.22)	**4.99** (3.43-7.10)	**22.5** (17.1-34.4)	**103** (72.0-152)	**228** (177-259)	826
	01-02	**4.13** (3.43-4.96)	**3.40** (2.60-4.40)	**17.9** (15.5-23.8)	**98.7** (67.4-153)	**260** (153-526)	1222
	03-04	**5.27** (4.63-5.99)	**5.30** (4.40-6.00)	**24.2** (18.8-28.5)	**99.5** (67.6-149)	**246** (183-409)	1070

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.2, 0.4, and 0.4, respectively.

postmenopausal Finnish women who were omnivores and vegetarians (Uehara et al., 2000*a,b*). Vegetarian women in Boston and Helsinki (Adlercreutz et al., 1986), men and women consuming an experimental cruciferous diet (Kirkman et al., 1995), and Boston women consuming a macrobiotic diet excreted significantly higher urinary levels of these lignans (Hutchins, 1995a). Urinary enterolactone and enterodiol levels have been reported to vary by age, gender, race/ethnicity, and income (Valentin-Blasini et al., 2003). Men were shown to have higher urinary mean levels of the isoflavones and higher levels of total phytoestrogens when compared with women (Lampe et al., 1999).

Levels of isoflavones (daidzein, genistein, equol, and O-desmethylangolensin) in the NHANES 1999-2004 subsamples appeared broadly similar to those seen in young Caucasian, African-American, Latino, and Japanese women in the San Francisco Bay area (CDC, 2005; Horn-Ross et al., 1997); men and women in the United States (Valentin-Blasini et al., 2003; Lampe et al., 1999); Caucasian and Filipino women living in Hawaii (Maskarinec et al., 1998); postmenopausal women from Holland (den Tonkelaar et al., 2001) and the United Kingdom (Grace et al., 2004); omnivorous and vegetarian Helsinki women (Uehara et al., 2000 *a,b*); and premenopausal omnivorous Boston women (Hutchins, 1995*a,b*).

Isoflavone levels seen in the NHANES 1999-2004

Urinary O-Desmethylangolensin (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**4.03** (2.97-5.45)	**4.44** (3.10-6.34)	**21.8** (15.3-31.6)	**90.4** (62.9-122)	**167** (140-218)	2271
	01-02	**3.83** (3.32-4.43)	**3.24** (2.55-4.12)	**18.9** (16.1-23.3)	**85.2** (65.1-117)	**281** (149-412)	2794
	03-04	**4.58** (4.20-5.01)	**4.09** (3.53-4.59)	**19.6** (17.4-22.6)	**92.9** (76.5-120)	**201** (183-261)	2581
Age group							
6-11 years	99-00	**6.00** (4.04-8.91)	**7.15** (3.94-16.6)	**28.8** (14.3-45.0)	**83.3** (45.0-167)	**179** (88.2-262)	287
	01-02	**7.03** (5.05-9.77)	**6.49** (4.24-11.6)	**29.9** (16.3-54.1)	**101** (75.3-199)	**305** (134-464)	396
	03-04	**6.73** (4.55-9.97)	**5.97** (4.09-8.28)	**27.7** (15.6-42.3)	**86.1** (45.2-135)	**149** (84.3-189)	341
12-19 years	99-00	**4.13** (2.33-7.35)	**5.71** (2.82-11.5)	**26.0** (14.7-44.4)	**71.4** (40.8-122)	**122** (75.2-262)	667
	01-02	**4.57** (3.44-6.07)	**3.88** (2.82-5.32)	**26.0** (18.0-35.9)	**95.0** (61.4-129)	**259** (129-331)	744
	03-04	**4.76** (3.71-6.11)	**4.26** (3.13-5.97)	**22.9** (14.3-39.2)	**86.4** (49.0-149)	**185** (101-261)	729
20 years and older	99-00	**3.82** (2.84-5.13)	**3.90** (2.69-5.73)	**20.2** (12.9-29.2)	**96.5** (61.8-133)	**172** (140-252)	1317
	01-02	**3.46** (2.95-4.04)	**2.74** (2.03-3.64)	**16.8** (13.7-20.3)	**78.9** (58.2-124)	**281** (143-467)	1654
	03-04	**4.35** (3.96-4.78)	**3.75** (3.23-4.35)	**18.7** (15.7-22.6)	**95.2** (76.5-131)	**228** (192-284)	1511
Gender							
Males	99-00	**3.95** (2.79-5.58)	**4.50** (2.88-6.50)	**24.5** (13.8-40.5)	**96.5** (62.4-122)	**210** (125-265)	1087
	01-02	**3.10** (2.48-3.86)	**2.87** (2.00-3.96)	**15.0** (10.4-19.7)	**60.7** (41.5-90.2)	**154** (96.4-301)	1375
	03-04	**3.83** (3.10-4.73)	**3.33** (2.41-4.35)	**15.6** (13.9-19.0)	**76.2** (51.1-99.5)	**193** (124-255)	1240
Females	99-00	**4.10** (3.00-5.61)	**4.17** (2.91-6.34)	**20.4** (14.4-27.2)	**86.0** (49.1-145)	**155** (100-205)	1184
	01-02	**4.68** (3.87-5.68)	**3.74** (2.77-4.88)	**26.8** (18.7-34.0)	**111** (70.3-205)	**399** (175-739)	1419
	03-04	**5.45** (4.71-6.30)	**4.81** (4.09-5.92)	**24.3** (19.6-28.9)	**106** (78.5-163)	**255** (193-343)	1341
Race/ethnicity							
Mexican Americans	99-00	**2.19** (1.49-3.24)	**1.88** (1.15-3.10)	**16.6** (11.3-25.8)	**71.2** (52.3-113)	**136** (90.5-251)	721
	01-02	**2.30** (1.48-3.57)	**1.45** (.770-3.37)	**11.8** (4.91-23.6)	**46.7** (31.4-87.8)	**108** (54.7-218)	679
	03-04	**2.30** (1.68-3.15)	**1.65** (.850-3.06)	**13.2** (6.63-21.2)	**51.6** (36.9-75.4)	**125** (84.1-165)	652
Non-Hispanic blacks	99-00	**3.65** (2.90-4.60)	**5.22** (3.58-6.75)	**23.8** (17.6-32.1)	**67.1** (52.1-79.7)	**116** (81.9-239)	538
	01-02	**3.75** (2.76-5.10)	**3.56** (2.14-5.48)	**22.8** (14.5-30.4)	**78.5** (46.5-175)	**218** (98.5-339)	706
	03-04	**3.89** (3.03-4.99)	**3.12** (1.96-4.96)	**17.0** (11.3-26.7)	**80.0** (58.6-104)	**159** (120-255)	698
Non-Hispanic whites	99-00	**4.42** (3.12-6.27)	**4.68** (3.05-7.23)	**22.3** (15.3-37.9)	**102** (57.6-148)	**177** (140-215)	826
	01-02	**4.08** (3.41-4.89)	**3.51** (2.45-4.57)	**21.2** (16.3-27.4)	**96.4** (69.8-126)	**300** (153-464)	1222
	03-04	**5.18** (4.70-5.70)	**4.58** (3.89-5.39)	**21.6** (17.4-27.7)	**103** (77.7-149)	**225** (185-272)	1070

subsamples were 4 to 50 times lower than levels observed in Japanese men and women (Adlercreutz et al., 1991; CDC, 2005; Uehara et al., 2000*a*); Japanese women (Arai et al., 2000); postmenopausal Chinese women (Zheng et al., 1999); Singaporean women (Chen et al., 1999; Seow et al., 1998); and Japanese women living in Hawaii (Maskarinec et al., 1998). Genistein and daidzein levels in NHANES 1999-2004 subsamples were twice as high as levels reported in people consuming a carotenoid diet, but lower than levels found in people consuming a cruciferous diet; O-desmethylangolensin levels were seven times lower (Kirkman et al., 1995). Levels of genistein, daidzein, and O-desmethylangolensin in urine of people consuming a soy diet were 6 to 100 times higher than levels found in NHANES 1999-2004 subsamples (CDC, 2005). Supplementing an omnivorous U.S. diet over a three month period with 60 grams of soy powder for female subjects increased isoflavone levels by more than thirteen-fold. (Albertazzi et al., 1999). Among U.S. adults, non-Hispanic whites were reported to have higher urinary isoflavone levels than non-Hispanic blacks or Hispanics (Valentin-Blasini et al., 2003).

Finding a measurable amount of one or more phytoestrogen metabolites in urine does not mean that the levels of the metabolites or the parent phytoestrogen cause an adverse health effect. Biomonitoring studies on the levels of phytoestrogen metabolites provide physicians and public

Urinary Enterodiol

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**26.6** (21.9-32.3)	**34.0** (29.4-38.7)	**78.8** (62.6-95.5)	**165** (135-215)	**266** (215-335)	2527
	01-02	**35.7** (32.5-39.3)	**39.4** (36.3-43.4)	**89.2** (80.7-96.9)	**181** (162-205)	**253** (223-308)	2794
	03-04	**39.5** (36.1-43.3)	**44.9** (40.6-50.3)	**106** (97.2-115)	**242** (212-264)	**367** (311-423)	2594
Age group							
6-11 years	99-00	**26.5** (17.1-41.0)	**29.4** (21.2-44.2)	**78.7** (44.2-109)	**215** (91.1-279)	**276** (131-458)	327
	01-02	**33.6** (29.8-37.8)	**35.5** (29.4-43.7)	**78.1** (63.8-87.0)	**152** (113-171)	**203** (167-327)	396
	03-04	**42.0** (34.5-51.1)	**42.1** (34.4-49.2)	**91.4** (74.4-110)	**199** (126-289)	**312** (217-525)	341
12-19 years	99-00	**29.8** (23.8-37.2)	**34.0** (27.4-42.0)	**84.4** (59.1-101)	**166** (112-234)	**253** (182-337)	744
	01-02	**35.3** (30.5-40.9)	**37.7** (34.8-43.4)	**84.2** (72.1-96.9)	**165** (128-206)	**238** (169-343)	744
	03-04	**45.1** (39.4-51.6)	**46.3** (38.7-56.9)	**99.5** (84.9-109)	**191** (161-269)	**325** (275-415)	729
20 years and older	99-00	**26.1** (21.8-31.3)	**34.3** (29.8-38.7)	**78.3** (63.5-94.8)	**160** (132-196)	**263** (189-335)	1456
	01-02	**36.1** (31.8-41.0)	**40.4** (36.0-45.7)	**91.2** (79.3-105)	**190** (161-220)	**256** (224-312)	1654
	03-04	**38.4** (34.2-43.0)	**44.9** (40.1-51.9)	**112** (98.8-125)	**255** (215-274)	**398** (320-448)	1524
Gender							
Males	99-00	**25.3** (19.5-32.7)	**33.0** (28.0-38.0)	**72.6** (54.7-94.3)	**149** (109-219)	**258** (169-286)	1206
	01-02	**35.2** (31.8-39.1)	**40.5** (36.8-44.8)	**90.6** (82.3-103)	**184** (158-198)	**263** (223-338)	1375
	03-04	**39.7** (36.2-43.6)	**45.1** (40.5-51.1)	**102** (92.9-115)	**231** (186-266)	**361** (268-460)	1244
Females	99-00	**27.9** (23.4-33.3)	**36.0** (29.9-40.3)	**84.4** (71.8-97.9)	**177** (146-219)	**280** (219-375)	1321
	01-02	**36.2** (32.2-40.7)	**38.5** (35.3-43.4)	**87.0** (75.6-98.5)	**175** (152-212)	**248** (220-283)	1419
	03-04	**39.3** (33.8-45.5)	**44.9** (38.3-53.0)	**110** (97.3-124)	**250** (203-294)	**398** (309-464)	1350
Race/ethnicity							
Mexican Americans	99-00	**21.7** (19.5-24.1)	**28.0** (24.7-34.7)	**70.4** (60.8-78.8)	**143** (117-169)	**213** (169-256)	791
	01-02	**30.5** (25.7-36.3)	**34.0** (29.0-39.2)	**75.9** (58.8-89.7)	**159** (119-202)	**244** (192-298)	679
	03-04	**33.1** (26.4-41.6)	**38.7** (31.2-47.6)	**95.2** (78.1-115)	**198** (125-307)	**307** (186-480)	653
Non-Hispanic blacks	99-00	**25.8** (21.7-30.7)	**31.2** (24.4-35.9)	**66.0** (50.2-86.7)	**157** (122-193)	**260** (185-336)	608
	01-02	**35.0** (28.9-42.3)	**38.7** (33.2-49.2)	**83.7** (70.0-103)	**169** (132-191)	**225** (175-339)	706
	03-04	**40.4** (34.9-46.7)	**47.1** (40.4-53.7)	**100** (81.3-123)	**212** (157-254)	**293** (232-417)	699
Non-Hispanic whites	99-00	**29.2** (24.0-35.4)	**37.6** (31.3-43.8)	**85.8** (68.3-99.4)	**171** (138-228)	**270** (187-375)	915
	01-02	**35.6** (31.8-40.0)	**40.4** (36.1-44.7)	**89.6** (78.5-101)	**175** (153-198)	**254** (214-337)	1222
	03-04	**39.8** (35.5-44.7)	**45.8** (38.9-54.9)	**109** (95.8-126)	**255** (206-267)	**365** (294-424)	1079

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.8, 1.5, and 1.5, respectively.

health officials with reference values so that they can determine whether people have been exposed to higher levels of phytoestrogens than those found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary Enterodiol (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**24.2** (20.3-28.9)	**29.9** (25.0-34.7)	**70.5** (59.6-82.1)	**146** (124-177)	**240** (199-320)	2527
	01-02	**33.5** (30.7-36.7)	**37.6** (33.0-42.1)	**79.2** (72.6-87.3)	**149** (136-164)	**224** (197-250)	2794
	03-04	**37.0** (33.6-40.7)	**41.7** (37.9-45.4)	**95.9** (85.6-106)	**194** (171-213)	**294** (247-368)	2594
Age group							
6-11 years	99-00	**27.0** (18.6-39.3)	**33.7** (21.8-43.7)	**62.7** (43.0-108)	**168** (81.6-290)	**290** (150-411)	327
	01-02	**38.1** (32.5-44.7)	**39.3** (30.8-53.1)	**78.3** (66.6-103)	**188** (147-244)	**304** (242-389)	396
	03-04	**44.7** (37.4-53.5)	**46.6** (38.5-58.3)	**93.3** (73.9-125)	**177** (128-205)	**215** (181-413)	341
12-19 years	99-00	**20.1** (16.7-24.2)	**24.1** (19.6-30.1)	**55.1** (42.6-71.7)	**99.5** (91.5-116)	**158** (121-177)	744
	01-02	**27.2** (23.3-31.8)	**28.7** (24.9-34.9)	**62.7** (54.9-71.0)	**104** (84.2-139)	**152** (111-225)	744
	03-04	**33.8** (30.3-37.7)	**34.8** (33.2-38.8)	**67.6** (64.1-73.9)	**130** (107-164)	**221** (138-324)	729
20 years and older	99-00	**24.7** (20.6-29.5)	**30.6** (26.0-34.8)	**73.0** (62.5-84.5)	**157** (129-184)	**242** (199-344)	1456
	01-02	**34.2** (30.3-38.5)	**39.6** (32.5-45.3)	**84.1** (73.8-93.3)	**152** (136-169)	**224** (193-250)	1654
	03-04	**36.7** (32.5-41.4)	**42.0** (37.1-47.8)	**103** (91.8-111)	**205** (173-239)	**327** (256-431)	1524
Gender							
Males	99-00	**19.8** (15.4-25.4)	**25.4** (20.0-31.4)	**55.1** (46.4-64.2)	**122** (94.6-168)	**199** (145-282)	1206
	01-02	**28.7** (26.0-31.7)	**31.4** (27.0-36.8)	**71.3** (64.2-78.0)	**136** (114-160)	**212** (179-259)	1375
	03-04	**31.1** (27.5-35.0)	**34.8** (32.3-38.5)	**78.0** (68.8-92.7)	**165** (128-211)	**249** (187-361)	1244
Females	99-00	**29.3** (25.0-34.4)	**35.4** (29.5-41.6)	**85.2** (74.5-92.3)	**165** (141-201)	**321** (226-370)	1321
	01-02	**38.9** (34.9-43.3)	**43.9** (39.3-48.7)	**88.3** (74.7-102)	**157** (139-174)	**235** (180-304)	1419
	03-04	**43.6** (38.3-49.7)	**49.0** (43.4-57.7)	**109** (98.8-123)	**215** (178-270)	**377** (278-443)	1350
Race/ethnicity							
Mexican Americans	99-00	**19.6** (17.3-22.2)	**23.5** (19.7-28.7)	**60.6** (49.8-77.7)	**134** (114-154)	**193** (154-227)	791
	01-02	**28.7** (24.5-33.7)	**31.0** (27.0-37.3)	**64.1** (55.0-77.5)	**133** (94.4-183)	**223** (143-337)	679
	03-04	**29.9** (23.8-37.4)	**34.0** (26.5-42.8)	**74.1** (62.0-101)	**176** (118-234)	**241** (189-364)	653
Non-Hispanic blacks	99-00	**16.6** (13.9-19.7)	**18.8** (14.4-22.9)	**47.3** (37.7-55.8)	**113** (85.9-145)	**169** (131-272)	608
	01-02	**24.5** (19.7-30.6)	**27.0** (22.6-33.4)	**57.5** (48.2-73.2)	**117** (92.2-143)	**157** (118-246)	706
	03-04	**28.6** (24.5-33.4)	**30.4** (26.1-36.1)	**68.3** (53.4-87.5)	**126** (96.3-191)	**203** (153-227)	699
Non-Hispanic whites	99-00	**28.6** (24.3-33.6)	**34.4** (28.9-39.3)	**75.8** (65.3-87.2)	**163** (130-197)	**252** (203-363)	915
	01-02	**35.3** (31.6-39.4)	**40.9** (34.3-46.8)	**83.3** (74.7-90.3)	**152** (136-173)	**225** (189-275)	1222
	03-04	**39.3** (34.4-44.8)	**45.5** (38.4-53.0)	**105** (90.2-116)	**202** (168-234)	**299** (244-374)	1079

Urinary Enterolactone

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**239** (200-286)	**315** (245-381)	**726** (595-879)	**1970** (1440-2370)	**2800** (2500-3140)	2548
	01-02	**259** (233-287)	**350** (314-389)	**807** (739-873)	**1590** (1440-1820)	**2720** (1870-3430)	2794
	03-04	**298** (265-334)	**395** (331-464)	**900** (819-969)	**1790** (1560-2040)	**2620** (2360-2880)	2594
Age group							
6-11 years	99-00	**308** (219-432)	**356** (243-474)	**721** (520-1320)	**1730** (973-2840)	**2840** (1700-3590)	331
	01-02	**288** (245-339)	**329** (271-412)	**680** (566-794)	**1380** (929-1620)	**2200** (1420-2550)	396
	03-04	**384** (287-513)	**414** (299-567)	**926** (589-1190)	**1660** (1140-2280)	**2360** (1700-3440)	341
12-19 years	99-00	**250** (191-327)	**317** (242-410)	**672** (454-888)	**1760** (973-2480)	**2920** (1950-4330)	746
	01-02	**267** (231-308)	**321** (255-399)	**729** (617-856)	**1480** (1230-1800)	**2180** (1560-3440)	744
	03-04	**314** (267-369)	**400** (333-468)	**866** (736-1050)	**1690** (1410-2080)	**2620** (2000-2890)	729
20 years and older	99-00	**230** (193-274)	**310** (242-375)	**734** (599-888)	**2000** (1490-2390)	**2790** (2510-3540)	1471
	01-02	**254** (223-289)	**357** (314-397)	**835** (760-914)	**1660** (1460-1890)	**2840** (1890-3610)	1654
	03-04	**286** (253-324)	**394** (311-465)	**900** (824-960)	**1820** (1560-2060)	**2630** (2350-3100)	1524
Gender							
Males	99-00	**254** (212-304)	**351** (266-418)	**778** (579-1050)	**2000** (1580-2400)	**2730** (2430-3350)	1219
	01-02	**262** (233-295)	**340** (314-387)	**873** (769-957)	**1810** (1490-2470)	**3050** (1990-4070)	1375
	03-04	**314** (280-351)	**425** (376-477)	**938** (840-1060)	**1760** (1540-2050)	**2620** (2060-3230)	1244
Females	99-00	**226** (180-284)	**287** (236-339)	**684** (560-799)	**1890** (1200-2460)	**2830** (2100-4330)	1329
	01-02	**255** (226-288)	**357** (298-397)	**759** (680-840)	**1450** (1190-1700)	**2200** (1710-2950)	1419
	03-04	**283** (233-343)	**371** (278-465)	**859** (706-984)	**1810** (1440-2170)	**2630** (2210-3440)	1350
Race/ethnicity							
Mexican Americans	99-00	**212** (169-265)	**281** (230-335)	**631** (539-732)	**1650** (950-2210)	**2690** (2380-3350)	813
	01-02	**275** (221-342)	**347** (312-395)	**778** (671-913)	**1520** (1090-1920)	**2340** (1610-2990)	679
	03-04	**275** (239-316)	**376** (316-435)	**849** (744-958)	**1560** (1320-1860)	**2240** (1860-3100)	653
Non-Hispanic blacks	99-00	**262** (196-349)	**363** (293-440)	**759** (629-925)	**1730** (1000-2420)	**2500** (1870-3280)	605
	01-02	**278** (226-342)	**418** (341-479)	**769** (686-853)	**1450** (1160-1840)	**2000** (1540-2420)	706
	03-04	**328** (285-378)	**437** (362-526)	**942** (768-1110)	**1580** (1360-1820)	**2280** (1880-2640)	699
Non-Hispanic whites	99-00	**247** (196-311)	**317** (240-403)	**752** (616-955)	**2040** (1600-2450)	**3000** (2460-3880)	917
	01-02	**267** (235-303)	**357** (307-397)	**834** (750-923)	**1630** (1420-1890)	**2780** (1820-3740)	1222
	03-04	**299** (254-352)	**396** (299-488)	**900** (789-996)	**1810** (1510-2140)	**2680** (2310-3230)	1079

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.6, 1.9, and 1.9, respectively.

Urinary Enterolactone (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**218** (184-260)	**284** (247-336)	**733** (613-869)	**1580** (1290-1830)	**2250** (1860-2830)	2548
	01-02	**243** (220-268)	**324** (293-360)	**756** (668-858)	**1430** (1250-1580)	**2120** (1720-2450)	2794
	03-04	**279** (245-317)	**371** (324-430)	**810** (697-911)	**1590** (1350-1910)	**2400** (2000-2890)	2594
Age group							
6-11 years	99-00	**315** (238-416)	**384** (266-435)	**704** (495-1110)	**1580** (1110-2010)	**2100** (1580-3040)	331
	01-02	**327** (274-391)	**349** (263-478)	**738** (603-994)	**1420** (1140-1800)	**2020** (1420-2940)	396
	03-04	**409** (310-540)	**470** (354-632)	**904** (669-1150)	**1480** (1090-2420)	**2300** (1480-2690)	341
12-19 years	99-00	**169** (133-214)	**210** (172-264)	**486** (371-615)	**1150** (742-1540)	**1850** (1310-2350)	746
	01-02	**206** (178-239)	**255** (223-293)	**619** (466-753)	**1110** (869-1480)	**1500** (1140-2080)	744
	03-04	**235** (202-273)	**285** (255-307)	**631** (533-744)	**1230** (993-1350)	**1510** (1240-2230)	729
20 years and older	99-00	**217** (181-261)	**288** (249-350)	**785** (653-923)	**1640** (1330-1890)	**2310** (1890-3110)	1471
	01-02	**240** (213-271)	**331** (300-375)	**786** (672-915)	**1460** (1300-1630)	**2180** (1890-2470)	1654
	03-04	**274** (236-318)	**377** (316-448)	**823** (697-937)	**1700** (1430-1980)	**2480** (2040-3100)	1524
Gender							
Males	99-00	**199** (170-234)	**263** (228-309)	**664** (490-828)	**1380** (1200-1710)	**2030** (1780-2480)	1219
	01-02	**213** (191-238)	**287** (255-316)	**682** (601-764)	**1350** (1090-1580)	**1980** (1570-2550)	1375
	03-04	**245** (215-280)	**330** (288-372)	**729** (676-808)	**1330** (1160-1580)	**2040** (1590-2380)	1244
Females	99-00	**238** (191-297)	**303** (260-379)	**819** (662-968)	**1720** (1390-2010)	**2550** (1940-3390)	1329
	01-02	**274** (241-312)	**356** (313-407)	**833** (710-1000)	**1490** (1320-1670)	**2150** (1890-2410)	1419
	03-04	**314** (257-385)	**414** (327-510)	**866** (704-1090)	**1840** (1460-2280)	**2840** (2220-3910)	1350
Race/ethnicity							
Mexican Americans	99-00	**194** (165-228)	**254** (225-282)	**605** (519-695)	**1340** (969-1740)	**2100** (1620-2790)	813
	01-02	**259** (213-314)	**362** (296-409)	**730** (586-905)	**1240** (1010-1490)	**1630** (1240-2540)	679
	03-04	**248** (217-282)	**350** (310-403)	**724** (657-826)	**1320** (1020-1560)	**1820** (1460-2170)	653
Non-Hispanic blacks	99-00	**168** (125-226)	**214** (173-274)	**546** (411-732)	**1130** (874-1450)	**1590** (1120-2560)	605
	01-02	**195** (155-245)	**302** (257-331)	**562** (470-629)	**985** (821-1130)	**1490** (1080-1730)	706
	03-04	**233** (197-274)	**303** (276-347)	**621** (512-707)	**1050** (917-1350)	**1550** (1170-2220)	699
Non-Hispanic whites	99-00	**241** (194-300)	**323** (279-388)	**828** (674-997)	**1780** (1390-2020)	**2490** (1930-3340)	917
	01-02	**264** (232-301)	**339** (299-393)	**833** (719-944)	**1530** (1340-1880)	**2410** (1940-2800)	1222
	03-04	**294** (246-353)	**399** (326-488)	**836** (707-980)	**1660** (1330-2040)	**2500** (1990-3350)	1079

Urinary Equol

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**8.37** (7.21-9.72)	**8.02** (6.27-9.90)	**17.2** (15.2-19.8)	**35.0** (28.9-41.6)	**53.7** (40.1-74.2)	2182
	01-02	**9.17** (7.76-10.8)	**9.00** (7.40-10.5)	**19.6** (16.6-23.5)	**42.1** (34.3-51.5)	**73.5** (53.6-89.2)	2794
	03-04	**8.02** (7.07-9.10)	**8.00** (6.80-9.40)	**18.2** (15.2-20.8)	**36.6** (31.3-40.0)	**64.9** (45.4-97.9)	2590
Age group							
6-11 years	99-00	**10.5** (7.65-14.3)	**11.7** (5.43-18.6)	**24.9** (17.5-29.5)	**34.4** (29.5-53.3)	**56.1** (30.1-149)	272
	01-02	**12.2** (10.2-14.6)	**13.7** (11.1-16.2)	**26.2** (17.9-37.9)	**50.4** (35.0-84.3)	**85.4** (50.4-159)	396
	03-04	**12.4** (9.71-15.8)	**12.1** (8.40-17.8)	**24.4** (20.1-31.2)	**46.7** (33.5-82.3)	**85.8** (44.9-118)	341
12-19 years	99-00	**10.9** (8.64-13.8)	**10.8** (8.52-13.4)	**22.3** (16.0-34.9)	**42.9** (34.1-71.3)	**71.6** (48.1-210)	657
	01-02	**10.2** (8.50-12.1)	**10.5** (8.20-12.5)	**20.5** (16.8-24.8)	**43.1** (30.1-56.1)	**70.0** (46.3-99.2)	744
	03-04	**10.6** (8.97-12.4)	**10.5** (8.70-12.2)	**22.6** (19.3-26.4)	**39.9** (34.8-45.1)	**61.9** (45.1-113)	729
20 years and older	99-00	**7.79** (6.79-8.94)	**7.43** (5.71-8.85)	**16.0** (13.6-18.1)	**33.1** (24.4-39.7)	**52.2** (36.3-93.9)	1253
	01-02	**8.70** (7.29-10.4)	**8.00** (6.20-10.2)	**18.6** (15.0-22.3)	**41.3** (34.1-47.4)	**73.5** (53.9-89.0)	1654
	03-04	**7.28** (6.37-8.33)	**7.20** (6.00-8.70)	**16.0** (14.2-19.2)	**33.9** (28.2-38.9)	**63.0** (41.3-121)	1520
Gender							
Males	99-00	**9.15** (7.37-11.4)	**8.44** (6.36-11.2)	**19.0** (15.9-24.0)	**35.6** (29.2-54.8)	**71.3** (39.7-166)	1042
	01-02	**9.41** (7.99-11.1)	**9.20** (7.70-10.8)	**20.1** (16.7-26.1)	**43.1** (32.4-53.1)	**61.7** (51.8-81.5)	1375
	03-04	**8.56** (7.54-9.72)	**8.70** (7.20-10.2)	**19.0** (15.9-21.6)	**38.0** (31.9-44.2)	**72.6** (45.4-100)	1240
Females	99-00	**7.70** (6.79-8.75)	**7.57** (5.79-9.04)	**15.6** (12.7-18.9)	**33.6** (26.7-37.7)	**48.2** (37.1-62.9)	1140
	01-02	**8.94** (7.38-10.8)	**8.60** (6.70-10.7)	**19.0** (15.6-22.9)	**41.6** (33.3-51.5)	**79.8** (56.6-122)	1419
	03-04	**7.55** (6.44-8.84)	**7.30** (6.20-9.00)	**16.9** (14.7-19.8)	**33.8** (28.3-40.0)	**60.3** (42.5-116)	1350
Race/ethnicity							
Mexican Americans	99-00	**5.24** (4.77-5.76)	**4.51** (3.65-5.18)	**9.48** (7.96-10.3)	**18.5** (14.5-22.6)	**30.9** (21.6-48.4)	726
	01-02	**7.22** (6.04-8.62)	**6.50** (4.40-9.10)	**14.2** (11.3-20.1)	**31.4** (21.1-41.0)	**42.4** (38.1-60.2)	679
	03-04	**6.08** (5.08-7.28)	**5.70** (4.70-6.80)	**12.5** (9.80-15.4)	**26.1** (18.1-39.7)	**43.6** (34.3-88.2)	653
Non-Hispanic blacks	99-00	**6.73** (5.20-8.71)	**6.24** (3.86-10.0)	**15.1** (12.7-17.6)	**27.6** (19.4-35.6)	**36.4** (28.9-49.4)	514
	01-02	**7.15** (6.06-8.43)	**6.10** (4.70-7.60)	**14.7** (12.0-18.7)	**30.9** (22.8-41.9)	**45.7** (36.1-90.5)	706
	03-04	**7.35** (6.16-8.79)	**7.90** (6.00-9.60)	**16.5** (14.2-18.3)	**32.0** (25.1-37.5)	**47.0** (37.8-68.2)	696
Non-Hispanic whites	99-00	**9.26** (7.80-11.0)	**8.98** (6.73-11.9)	**19.0** (16.1-22.8)	**36.2** (30.1-45.4)	**56.1** (42.1-89.4)	758
	01-02	**9.91** (7.95-12.4)	**10.0** (7.30-12.6)	**22.0** (17.4-27.4)	**44.4** (35.1-57.5)	**74.4** (55.1-107)	1222
	03-04	**8.52** (7.26-10.0)	**8.80** (7.10-10.3)	**19.3** (15.4-23.0)	**37.7** (31.7-44.2)	**73.1** (46.7-120)	1078

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 3.0, 3.3, and 3.3, respectively.

Urinary Equol (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**7.70** (6.82-8.70)	**7.96** (6.87-9.35)	**16.2** (13.2-18.6)	**30.6** (26.9-35.1)	**50.3** (41.8-67.3)	2182
	01-02	**8.60** (7.26-10.2)	**7.98** (6.62-9.76)	**17.6** (14.8-21.8)	**37.8** (30.3-46.3)	**62.6** (50.0-85.0)	2794
	03-04	**7.52** (6.83-8.29)	**7.29** (6.56-8.18)	**14.6** (13.3-15.7)	**27.8** (24.7-31.9)	**50.6** (39.9-75.1)	2590
Age group							
6-11 years	99-00	**10.3** (7.83-13.5)	**11.4** (7.46-16.3)	**22.6** (14.7-27.2)	**32.7** (25.5-46.0)	**47.8** (32.7-150)	272
	01-02	**13.9** (11.2-17.2)	**14.0** (10.6-17.0)	**28.8** (19.6-39.8)	**54.4** (34.9-99.8)	**88.2** (56.8-186)	396
	03-04	**13.2** (10.9-15.9)	**13.2** (9.19-17.5)	**24.2** (20.6-28.0)	**41.6** (35.2-64.1)	**93.5** (45.4-117)	341
12-19 years	99-00	**7.61** (6.17-9.39)	**8.02** (6.72-9.29)	**14.0** (11.4-20.4)	**27.5** (20.8-38.3)	**47.4** (27.5-149)	657
	01-02	**7.83** (6.68-9.17)	**7.77** (6.29-9.13)	**17.4** (14.9-19.2)	**31.9** (25.3-41.7)	**54.3** (33.0-76.7)	744
	03-04	**7.91** (6.59-9.49)	**8.11** (6.80-9.09)	**14.5** (11.8-17.5)	**30.1** (21.0-38.2)	**40.6** (32.6-66.9)	729
20 years and older	99-00	**7.45** (6.60-8.41)	**7.63** (6.34-9.22)	**15.3** (12.7-17.7)	**30.8** (25.0-37.2)	**53.2** (41.2-71.8)	1253
	01-02	**8.23** (6.93-9.79)	**7.52** (5.97-9.56)	**16.6** (14.0-20.8)	**36.4** (29.3-42.9)	**58.7** (47.9-85.0)	1654
	03-04	**6.98** (6.30-7.73)	**6.76** (6.05-7.65)	**13.6** (12.5-14.9)	**24.6** (21.9-29.4)	**42.8** (35.7-81.6)	1520
Gender							
Males	99-00	**7.01** (5.93-8.29)	**7.31** (5.63-8.78)	**13.8** (11.7-17.6)	**29.3** (21.4-41.8)	**54.1** (35.8-81.0)	1042
	01-02	**7.66** (6.39-9.18)	**7.43** (5.81-9.16)	**16.2** (14.0-19.4)	**32.9** (27.9-40.4)	**54.3** (37.8-67.1)	1375
	03-04	**6.71** (6.02-7.47)	**6.63** (5.78-7.29)	**13.3** (11.9-15.5)	**25.7** (23.1-30.3)	**51.1** (37.1-76.7)	1240
Females	99-00	**8.41** (7.33-9.66)	**8.71** (7.33-10.1)	**17.7** (15.1-20.0)	**31.6** (27.5-37.2)	**46.3** (41.0-56.5)	1140
	01-02	**9.60** (7.99-11.5)	**8.66** (6.97-10.6)	**19.2** (15.7-23.7)	**41.7** (32.3-55.9)	**85.0** (61.7-115)	1419
	03-04	**8.38** (7.39-9.51)	**8.29** (7.03-9.28)	**15.1** (14.0-16.6)	**30.6** (25.0-32.5)	**45.4** (38.7-102)	1350
Race/ethnicity							
Mexican Americans	99-00	**4.89** (4.36-5.47)	**4.73** (3.90-5.27)	**8.85** (8.18-9.91)	**22.3** (16.5-26.8)	**37.1** (25.3-57.6)	726
	01-02	**6.79** (5.82-7.92)	**6.81** (5.55-8.04)	**14.9** (11.7-17.8)	**29.1** (22.9-36.0)	**41.3** (31.4-47.1)	679
	03-04	**5.48** (4.60-6.54)	**4.72** (3.95-5.78)	**10.1** (7.76-13.4)	**24.4** (17.2-30.9)	**35.6** (27.6-102)	653
Non-Hispanic blacks	99-00	**4.36** (3.41-5.57)	**4.57** (2.94-6.23)	**10.2** (7.96-12.0)	**17.1** (14.8-19.8)	**26.0** (19.6-32.0)	514
	01-02	**5.01** (4.26-5.89)	**4.48** (3.80-5.42)	**11.0** (8.80-13.0)	**22.7** (16.5-29.3)	**35.4** (24.8-46.7)	706
	03-04	**5.23** (4.44-6.16)	**5.28** (4.67-6.09)	**10.3** (8.61-12.3)	**20.2** (17.1-23.9)	**29.4** (23.9-42.3)	696
Non-Hispanic whites	99-00	**9.13** (7.85-10.6)	**9.51** (7.63-11.2)	**18.0** (15.2-21.6)	**35.4** (29.5-41.3)	**56.5** (46.0-73.0)	758
	01-02	**9.81** (7.93-12.1)	**9.17** (7.06-12.2)	**19.8** (15.4-25.6)	**41.3** (30.7-55.9)	**66.4** (56.8-85.0)	1222
	03-04	**8.40** (7.50-9.41)	**8.17** (7.13-9.19)	**15.6** (14.1-17.1)	**30.6** (25.0-32.8)	**56.8** (38.0-107)	1078

Urinary Genistein

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**24.4** (19.7-30.3)	**27.0** (22.5-32.8)	**93.6** (75.8-118)	**284** (244-331)	**563** (413-709)	2557
	01-02	**33.0** (30.1-36.2)	**29.0** (26.8-31.8)	**92.5** (77.9-109)	**306** (240-372)	**619** (523-719)	2794
	03-04	**31.1** (29.0-33.3)	**26.2** (23.9-29.7)	**87.8** (78.8-102)	**286** (239-313)	**528** (402-610)	2594
Age group							
6-11 years	99-00	**27.6** (21.1-36.1)	**31.9** (18.1-42.6)	**104** (67.6-151)	**220** (151-315)	**376** (272-725)	331
	01-02	**39.2** (33.4-46.0)	**31.7** (25.8-39.6)	**94.1** (62.3-158)	**258** (190-426)	**502** (258-830)	396
	03-04	**33.6** (27.8-40.6)	**29.3** (23.1-37.8)	**79.4** (56.7-111)	**193** (146-274)	**351** (207-376)	341
12-19 years	99-00	**43.7** (34.2-55.7)	**45.4** (34.3-60.5)	**138** (93.7-179)	**319** (245-464)	**547** (321-777)	754
	01-02	**34.1** (27.2-42.8)	**29.0** (26.1-32.9)	**90.6** (71.5-113)	**278** (216-363)	**470** (360-687)	744
	03-04	**34.7** (29.3-41.0)	**29.0** (23.4-37.6)	**111** (69.3-141)	**304** (206-376)	**530** (358-671)	729
20 years and older	99-00	**21.9** (17.6-27.2)	**24.0** (21.7-28.4)	**86.2** (67.5-108)	**293** (235-343)	**566** (412-744)	1472
	01-02	**32.1** (28.8-35.8)	**28.8** (25.4-33.4)	**93.4** (77.3-110)	**312** (235-389)	**627** (537-790)	1654
	03-04	**30.2** (27.8-32.8)	**25.9** (22.3-29.8)	**87.8** (77.9-103)	**296** (239-321)	**557** (412-653)	1524
Gender							
Males	99-00	**29.8** (22.2-40.0)	**31.9** (26.3-37.2)	**108** (79.1-151)	**335** (257-440)	**709** (437-981)	1222
	01-02	**32.2** (27.9-37.2)	**29.5** (25.4-33.7)	**91.2** (73.4-103)	**239** (190-331)	**474** (335-719)	1375
	03-04	**33.7** (29.6-38.4)	**27.3** (23.4-33.0)	**92.6** (68.6-124)	**310** (228-351)	**562** (443-653)	1244
Females	99-00	**20.3** (17.0-24.2)	**23.1** (20.1-26.3)	**84.7** (59.6-105)	**242** (203-288)	**446** (339-619)	1335
	01-02	**33.7** (30.9-36.8)	**28.7** (26.0-32.3)	**97.0** (79.9-118)	**387** (253-500)	**666** (598-807)	1419
	03-04	**28.7** (25.5-32.4)	**25.0** (22.4-28.4)	**85.0** (71.2-106)	**256** (218-308)	**467** (356-620)	1350
Race/ethnicity							
Mexican Americans	99-00	**31.1** (25.1-38.5)	**30.0** (25.1-37.3)	**117** (83.9-179)	**328** (248-479)	**573** (419-1180)	819
	01-02	**28.3** (22.0-36.4)	**25.6** (19.6-32.5)	**74.8** (48.8-111)	**225** (174-314)	**424** (323-523)	679
	03-04	**31.1** (27.5-35.2)	**25.2** (19.1-32.6)	**83.2** (63.6-120)	**319** (252-537)	**653** (537-851)	653
Non-Hispanic blacks	99-00	**26.7** (19.2-37.0)	**32.9** (24.4-41.5)	**103** (84.8-137)	**257** (213-367)	**495** (329-926)	608
	01-02	**37.6** (27.4-51.6)	**35.3** (23.6-49.5)	**95.5** (71.1-142)	**378** (192-530)	**598** (375-1120)	706
	03-04	**32.3** (24.0-43.4)	**27.4** (18.8-44.9)	**84.8** (60.5-113)	**279** (163-412)	**514** (323-852)	699
Non-Hispanic whites	99-00	**23.6** (19.1-29.3)	**25.6** (21.7-32.0)	**91.4** (68.0-122)	**288** (227-353)	**566** (395-734)	917
	01-02	**30.9** (27.8-34.4)	**27.6** (24.6-30.8)	**89.7** (71.1-105)	**278** (226-365)	**626** (485-755)	1222
	03-04	**30.8** (28.2-33.6)	**26.2** (22.6-31.0)	**93.6** (78.8-112)	**279** (225-313)	**504** (376-610)	1079

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 0.3, 0.8, and 0.8, respectively.

Urinary Genistein (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	**22.3** (17.7-28.1)	**23.8** (18.8-28.9)	**84.7** (67.2-105)	**222** (182-279)	**381** (334-497)	2557
	01-02	**30.9** (28.5-33.6)	**25.9** (23.4-29.2)	**83.3** (72.2-96.3)	**256** (211-296)	**427** (375-490)	2794
	03-04	**29.1** (27.3-31.0)	**24.6** (21.3-27.5)	**77.7** (67.3-90.9)	**231** (203-279)	**510** (388-619)	2594
Age group							
6-11 years	99-00	**28.3** (21.1-37.9)	**27.8** (15.8-41.3)	**94.3** (60.5-145)	**209** (148-317)	**490** (279-895)	331
	01-02	**44.5** (37.0-53.5)	**37.9** (29.7-49.0)	**112** (76.5-146)	**252** (173-371)	**504** (252-713)	396
	03-04	**35.8** (29.7-43.0)	**35.4** (24.9-43.2)	**78.6** (60.9-119)	**172** (130-243)	**297** (168-618)	341
12-19 years	99-00	**29.4** (22.3-38.8)	**32.0** (23.8-41.6)	**83.2** (64.1-104)	**184** (130-295)	**336** (184-816)	754
	01-02	**26.3** (21.3-32.5)	**21.0** (17.8-26.5)	**66.2** (47.9-91.5)	**200** (149-298)	**321** (261-435)	744
	03-04	**25.9** (21.8-30.9)	**21.8** (17.0-29.1)	**65.6** (51.0-83.1)	**201** (145-313)	**366** (297-455)	729
20 years and older	99-00	**20.6** (16.3-26.2)	**21.6** (17.7-26.2)	**83.1** (64.9-107)	**234** (190-287)	**381** (325-562)	1472
	01-02	**30.4** (27.6-33.4)	**24.8** (21.9-30.0)	**83.2** (68.5-99.0)	**269** (208-328)	**435** (374-518)	1654
	03-04	**28.9** (26.7-31.3)	**24.0** (20.1-27.5)	**78.5** (66.1-92.9)	**253** (209-302)	**542** (399-673)	1524
Gender							
Males	99-00	**23.3** (16.8-32.3)	**23.8** (17.5-32.2)	**86.2** (64.7-115)	**236** (178-330)	**523** (323-889)	1222
	01-02	**26.2** (23.1-29.8)	**22.1** (19.4-26.0)	**67.6** (57.4-78.1)	**186** (144-237)	**350** (278-418)	1375
	03-04	**26.4** (22.8-30.5)	**21.5** (17.3-26.2)	**70.1** (51.1-90.5)	**203** (159-235)	**415** (346-600)	1244
Females	99-00	**21.3** (17.5-26.0)	**23.2** (17.5-29.3)	**83.1** (57.2-106)	**211** (154-283)	**357** (283-398)	1335
	01-02	**36.2** (32.8-39.9)	**29.6** (25.2-34.3)	**107** (88.4-129)	**321** (269-355)	**547** (427-729)	1419
	03-04	**31.9** (28.7-35.5)	**27.1** (23.6-31.6)	**87.1** (71.1-102)	**278** (209-324)	**548** (363-763)	1350
Race/ethnicity							
Mexican Americans	99-00	**28.4** (23.3-34.7)	**27.9** (22.5-35.0)	**109** (91.5-137)	**257** (209-380)	**562** (257-981)	819
	01-02	**26.6** (21.6-32.9)	**21.0** (16.1-28.9)	**61.6** (50.6-76.8)	**205** (147-270)	**372** (271-479)	679
	03-04	**28.0** (24.8-31.8)	**23.5** (18.5-28.1)	**69.2** (52.3-92.8)	**254** (187-390)	**608** (417-764)	653
Non-Hispanic blacks	99-00	**17.1** (12.4-23.7)	**19.5** (15.7-26.1)	**59.5** (43.1-93.7)	**179** (132-245)	**299** (222-446)	608
	01-02	**26.4** (19.3-36.1)	**22.7** (16.4-33.6)	**69.4** (42.2-115)	**217** (139-317)	**384** (217-747)	706
	03-04	**22.8** (18.1-28.8)	**19.6** (14.3-27.1)	**55.0** (39.6-78.1)	**182** (107-240)	**311** (210-514)	699
Non-Hispanic whites	99-00	**23.2** (18.5-29.0)	**24.9** (19.0-31.7)	**86.1** (68.4-105)	**232** (178-295)	**381** (325-523)	917
	01-02	**30.6** (28.2-33.2)	**25.4** (22.7-29.5)	**82.0** (68.3-96.3)	**248** (207-320)	**427** (365-518)	1222
	03-04	**30.4** (27.9-33.0)	**26.2** (21.5-31.4)	**79.6** (69.1-99.6)	**238** (195-321)	**534** (352-688)	1079

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Polybrominated Diphenyl Ethers and 2,2’,4,4’,5,5’-Hexabromobiphenyl (BB-153)

General Information

Polybrominated diphenyl ethers (PBDEs) are a class of synthetic chemicals first produced commercially in the 1970s. They are added to products such as foam padding, textiles, or plastics to retard combustion. 2,2’,4,4’,5,5’-hexabromobiphenyl (BB-153) is a brominated biphenyl that was used as a flame retardant in the U.S. until the 1970s. Its use was phased out following an accidental contamination of cattle feed in the state of Michigan with the contamination extending to other animals, the environment, and into humans (Fries, 1985).

Three major commercial mixtures of PBDEs have been produced and used. These are named for the average number of bromines attached to the diphenyl ether structure, e.g., pentaBDE. The pentaBDE technical mixture contains 50-60% of PBDE congeners with five bromines, 24-38% with four bromines (tetraBDEs) and 4-8% with six bromines (hexaBDE), though reports on mixtures vary (Alaee et al., 2003; Birnbaum and Staskal, 2004; OECD, 1994). Commercial pentaBDEs are often added to polyurethane foams used in mattresses, upholstered furniture, and carpet padding. OctaBDE technical mixtures contain 10-12% of PBDE congeners with six bromines, 43-44% with seven bromines, 31-35% with eight bromines and 10-11% with nine bromines. OctaBDE mixtures are added to acrylonitrile-butadiene-styrene used in computer and appliance casings, and also to some polyolefins and nylon. DecaBDE is the most widely used PBDE globally and greater than 97% of its content includes PBDEs with ten bromines. It is added to polystyrene, polybutylene, nylon, polypropylene, and other thermoelastic polymers used in adhesives, wire insulation, casings for televisions and computers, and in some non-clothing textiles (OECD, 1994; Sjödin et al., 2003; WSDH, 2004). PBDEs are often combined with antimony trioxide to enhance the fire protection offered by the PBDEs. For example, protected polypropylene can contain 23% decaBDE and 8% antimony trioxide by weight. PBDE content in protected products varies from 3-33% (Gill et al., 2004).

PBDE production makes up about 25% of all fire retardant production. In 2000, global production was 67,000 metric tons annually with about 80% of the total being decaBDE (Birnbaum and Staskal, 2004; WSDH, 2004). Most of the pentaBDE produced has been used within the U.S. About 40% and 44% of the global production of octaBDE and decaBDE were also used in the U.S. Since PBDEs are not chemically bound to the flame-retarded material, they can enter the environment from volatilization, leaching, or degradation of PBDE-containing products (Gill et al., 2004). Also, PBDEs can enter the environment from manufacturer-related releases. When thermally decomposed, PBDEs can produce polybrominated dibenzo-*p*-dioxins and dibenzofurans (Watanabe and Sakai, 2003). Manufacturers of pentaBDE and octaBDE in the U.S. were to have phased out production of these chemicals by 2004 and U.S. EPA issued a rule to prevent new production (U.S. EPA, 2005). PBDEs are generally persistent in the environment and have been measured in aquatic sediments and aquatic and terrestrial animals, especially in fish where PBDEs are known to bioconcentrate. Several studies of stored biologic specimens have shown dramatic increases in PBDE concentrations over the last several decades, for example, in archived bird eggs (Norstrom et al., 2002).

Human exposure to PBDEs is thought to result from

Polybrominated Diphenyl Ethers in this *Report*

Polybrominated Diphenyl Ether (IUPAC number)	**CAS Number**
Serum 2,2',4’-Tribromodiphenyl ether (BDE 17)	147217-75-2
Serum 2,4,4’-Tribromodiphenyl ether (BDE 28)	41318-75-6
Serum 2,2’,4,4’-Tetrabromodiphenyl ether (BDE 47)	5436-43-1
Serum 2,3',4,4'-Tetrabromodiphenyl ether (BDE 66)	189084-61-5
Serum 2,2’,3,4,4’-Pentabromodiphenyl ether (BDE 85)	182346-21-0
Serum 2,2’,4,4’,5-Pentabromodiphenyl ether (BDE 99)	60328-60-9
Serum 2,2’,4,4’,6-Pentabromodiphenyl ether (BDE 100)	189084-64-8
Serum 2,2’,4,4’,5,5’-Hexabromodiphenyl ether (BDE 153)	68631-49-2
Serum 2,2’,4,4’,5,6’-Hexabromodiphenyl ether (BDE 154)	207122-15-4
Serum 2,2’,3,4,4’,5’,6-Heptabromodiphenyl ether (BDE 183)	207122-16-5

dietary sources, including fish, fatty foods, and mother's milk. However, oral ingestion from dust and leachates may be a larger source (Sjödin et al, 2004*b*), particularly for children (Jones-Otazo et al., 2005; Stapleton et al., 2005). Once absorbed, PBDEs distribute into body fat. The metabolism and elimination of PBDEs in humans are not well characterized. One occupational study indicated that decaBDE has an elimination half-life of 11-18 days and the octaBDEs have half-lives ranging between 37-91 days (Thuresson et al., 2006). In animals, PBDE elimination occurs primarily through fecal excretion with decaBDE being more rapidly eliminated than the other less brominated PBDEs (Gill et al., 2004; Hardy, 2002). Some PBDEs measured in human serum are listed in the table.

Human health effects from PBDEs at low environmental doses or at biomonitored levels from low environmental exposures are unknown. In animal studies, PBDEs have low acute toxicity, but have demonstrated effects on thyroid function, neurodevelopment, hepatic enzyme induction and hepatic injury in subchronic or chronic dosing studies (Birnbaum and Staskal, 2004; Branchi et al., 2002; Gill et al., 2004; Hallgren and Darnerud, 2002; Viberg et al., 2003 and 2004; Zhou et al., 2002). Some developmental and behavioral effects may be mediated by the aforementioned effect on the thyroid, by alteration in cholinergic function (Branchi et al., 2003; Dufault et al., 2005), or by altered intracellular signaling within brain cells (Kodavanti et al., 2005). The lesser brominated PBDEs have been reported to have fetotoxic and reproductive effects, to alter expression of estrogen-regulated genes and receptors, and to have anti-androgenic effects (Ceccatelli et al., 2006; Gill et al., 2004; Kuriyama et al., 2005; Stoker et al., 2005; Talsness et al., 2005; WSDH, 2004). PentaBDE is considered more toxic than decaBDE and the most sensitive effects of pentaBDE in animal studies are neurodevelopmental and reproductive. In a study of electronics dismantlers, serum levels of PBDEs were not generally higher than in nonexposed workers and were not associated with changes in thyroid function (Julander et al., 2005). PBDEs are not considered genotoxic and are not classified by IARC and NTP with respect to human carcinogenicity. Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of PBDEs in serum reflect cumulative exposure over the recent months to years of exposure. The PBDE congeners measured for biomonitoring often include those containing three bromines (BDE-17, BDE-28), four bromines (BDE-47, BDE-66), five bromines (BDE-85, BDE-99, BDE-100), six bromines (BDE-153, BDE-154) and seven bromines (BDE-183). Analysis of the NHANES 2003-2004 subsample showed detection of BDE-47 (a tetraBDE present in commercial pentaBDEs) in nearly all participants and detection of BDE-28, BDE-99, BDE-100, and BDE-153 in greater than 60 percent of participants (Sjödin et al., 2008). Levels of these PBDEs tended to be well-correlated with each other. Serum levels of BDE-47, BDE-99, and BDE-153 were found to decrease with

Serum 2,2',4-Tribromodiphenyl ether (BDE 17) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1992
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	607
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1385
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	964
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1028
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	482
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	491
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	892

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.0.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

increasing age from 12-19 to 20-39 to 40-59 years, and then increase slightly in the 60 years and older age group. Slight differences by gender and race/ethnicity were also observed for several PBDEs (Sjödin et al., 2008).

From the 1970s to the late 1990s, levels of BDE-47 had increased in samples of breast milk and sera in Sweden and Norway, respectively (Meironyté et al., 1999; Thomsen et al., 2002). Also, in small samplings of residents in Japan and U.S., serum levels have been shown to increase by more than fivefold to twentyfold over the past two decades (Koizumi et al., 2005; Schecter et al., 2005; Sjödin et al., 2004*a*). Several small studies of U.S. residents have shown increasing levels of BDE-47 during recent decades that were 3-10 times higher than contemporary European residents (Petreas et al., 2003; Sjödin et al., 2003). Serum levels of PBDEs in the NHANES 2003-2004 subsample (Sjödin et al., 2008) also appeared generally higher than those reported for Japan, Sweden, and Norway (Koizumi et al., 2005; Thomsen et al., 2002; Thuresson et al., 2006). In most studies, BDE-47 demonstrates the highest levels of all the measured PBDEs.

Detection of BB-153 was also prevalent in the NHANES 2003-2004 subsample and increased with age (Sjödin et al., 2008). This age trend may be due to the longer time that BB-153 stays in the body or due to greater past exposures in older people. Mexican Americans and NHANES participants born in foreign countries had lower serum concentrations of BB-153 (Sjödin et al, 2008). Levels of BB-153 in NHANES 2003-2004 were about one-fourth to one-fortieth of the levels of BDE-47, depending on the age group. In human sera from Sweden, BB-153 was generally not detected as compared to detectable levels a small regional sample of U.S. residents (Sjödin et al., 2001).

Finding measurable amounts of PBDEs or BB-153 in serum does not mean that the levels of these chemicals cause an adverse health effect. Biomonitoring studies of serum PBDEs and BB-153 can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of PBDEs or BB-153 than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum 2,4,4'-Tribromodiphenyl ether (BDE 28) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**1.19** (1.03-1.37)	**1.10** (1.00-1.30)	**2.20** (1.90-2.60)	**4.80** (3.30-6.70)	**8.00** (5.40-11.3)	1987
Age group							
12-19 years	03-04	**1.30** (1.15-1.46)	**1.20** (1.10-1.50)	**2.40** (2.00-2.60)	**4.00** (2.90-5.60)	**6.10** (4.00-9.40)	598
20 years and older	03-04	**1.17** (1.01-1.37)	**1.10** (.900-1.30)	**2.20** (1.90-2.70)	**5.00** (3.30-7.20)	**8.20** (6.00-10.9)	1389
Gender							
Males	03-04	**1.21** (1.05-1.39)	**1.10** (1.00-1.30)	**2.30** (2.00-2.70)	**5.10** (3.50-7.30)	**8.20** (6.00-11.3)	964
Females	03-04	**1.17** (.990-1.38)	**1.10** (.900-1.40)	**2.10** (1.80-2.60)	**4.60** (3.00-6.90)	**7.80** (4.70-11.8)	1023
Race/ethnicity							
Mexican Americans	03-04	**1.43** (1.29-1.59)	**1.40** (1.20-1.50)	**2.40** (2.00-2.90)	**4.70** (3.70-5.50)	**7.30** (5.60-8.30)	488
Non-Hispanic blacks	03-04	**1.21** (1.03-1.42)	**1.10** (.900-1.30)	**2.20** (1.80-2.50)	**5.30** (3.50-6.70)	**8.40** (5.40-12.3)	470
Non-Hispanic whites	03-04	**1.17** (.968-1.42)	**1.10** (.900-1.30)	**2.20** (1.80-2.70)	**4.90** (3.00-8.00)	**8.00** (4.50-13.6)	905

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.8.

Serum 2,2',4,4'-Tetrabromodiphenyl ether (BDE 47) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**20.5** (17.6-23.9)	**19.2** (15.7-22.3)	**41.1** (35.6-49.2)	**85.1** (66.8-127)	**163** (108-240)	2016
Age group							
12-19 years	03-04	**28.2** (24.6-32.3)	**27.2** (22.1-33.6)	**53.6** (44.9-63.6)	**104** (82.4-145)	**174** (115-211)	615
20 years and older	03-04	**19.5** (16.5-23.1)	**18.0** (14.6-21.6)	**39.1** (32.8-47.0)	**83.3** (63.0-127)	**163** (102-240)	1401
Gender							
Males	03-04	**21.4** (18.1-25.3)	**19.2** (15.8-24.0)	**45.2** (37.3-54.9)	**94.3** (66.8-148)	**168** (112-382)	981
Females	03-04	**19.6** (16.4-23.5)	**19.1** (14.1-23.2)	**38.4** (31.8-46.4)	**79.5** (60.7-121)	**155** (102-239)	1035
Race/ethnicity							
Mexican Americans	03-04	**25.5** (23.0-28.1)	**23.6** (21.2-25.5)	**47.1** (38.2-56.5)	**87.2** (72.0-105)	**151** (105-195)	478
Non-Hispanic blacks	03-04	**24.3** (20.9-28.2)	**21.4** (18.2-25.6)	**47.5** (40.7-53.2)	**116** (81.8-149)	**242** (136-481)	499
Non-Hispanic whites	03-04	**19.5** (16.1-23.7)	**17.4** (14.4-22.2)	**40.2** (33.1-51.9)	**85.1** (60.3-142)	**163** (90.2-283)	912

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 4.2.

Serum 2,3',4,4'-Tetrabromodiphenyl ether (BDE 66) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	**1.30** (1.00-2.10)	1999
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	**1.30** (<LOD-1.90)	606
20 years and older	03-04	*	< LOD	< LOD	< LOD	**1.30** (1.00-2.20)	1393
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	**1.40** (1.00-2.60)	970
Females	03-04	*	< LOD	< LOD	< LOD	**1.10** (<LOD-2.20)	1029
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-1.60)	461
Non-Hispanic blacks	03-04	*	< LOD	< LOD	**1.00** (<LOD-2.00)	**2.40** (1.40-5.10)	496
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	**1.20** (<LOD-2.50)	914

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.0.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4'-Pentabromodiphenyl ether (BDE 85) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	**4.10** (2.80-6.30)	2000
Age group							
12-19 years	03-04	*	< LOD	< LOD	**2.80** (<LOD-3.50)	**4.00** (3.50-6.30)	610
20 years and older	03-04	*	< LOD	< LOD	< LOD	**4.10** (2.50-6.70)	1390
Gender							
Males	03-04	*	< LOD	< LOD	**2.40** (<LOD-3.30)	**4.80** (3.10-8.40)	967
Females	03-04	*	< LOD	< LOD	< LOD	**3.60** (<LOD-5.20)	1033
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	**3.70** (2.80-4.80)	484
Non-Hispanic blacks	03-04	*	< LOD	< LOD	**3.50** (2.50-4.40)	**6.90** (3.10-18.0)	493
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	**3.90** (<LOD-7.50)	895

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 2.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',5-Pentabromodiphenyl ether (BDE 99) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	**9.20** (7.50-11.1)	**21.7** (17.0-29.1)	**42.2** (33.3-54.8)	1985
Age group							
12-19 years	03-04	**6.88** (6.14-7.72)	**5.70** (<LOD-7.70)	**12.9** (11.4-15.7)	**27.9** (19.6-37.9)	**45.2** (35.9-56.8)	602
20 years and older	03-04	*	< LOD	**8.50** (7.10-10.5)	**20.6** (15.5-28.8)	**41.6** (30.8-57.3)	1383
Gender							
Males	03-04	**5.28** (<LOD-6.14)	< LOD	**10.0** (8.40-11.6)	**24.5** (18.0-37.3)	**45.5** (33.8-57.3)	964
Females	03-04	*	< LOD	**8.70** (6.60-10.6)	**18.3** (14.7-28.8)	**41.2** (22.9-60.3)	1021
Race/ethnicity							
Mexican Americans	03-04	**5.90** (5.45-6.39)	**5.50** (<LOD-5.80)	**10.8** (9.30-12.6)	**20.0** (17.0-23.5)	**30.8** (24.5-41.7)	478
Non-Hispanic blacks	03-04	**6.22** (5.42-7.12)	**5.00** (<LOD-5.70)	**11.5** (9.60-13.1)	**30.2** (21.5-42.2)	**74.7** (30.2-155)	479
Non-Hispanic whites	03-04	*	< LOD	**8.90** (6.80-11.3)	**21.7** (15.3-34.0)	**43.6** (30.7-71.4)	903

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 5.0.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',6-Pentabromodiphenyl ether (BDE 100) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**3.93** (3.42-4.51)	**3.60** (3.10-4.10)	**7.80** (6.80-9.00)	**18.4** (15.4-22.0)	**36.5** (24.6-54.0)	2040
Age group							
12-19 years	03-04	**5.17** (4.46-6.00)	**4.90** (3.80-6.10)	**9.50** (7.90-12.8)	**19.3** (14.4-26.2)	**34.3** (25.2-45.0)	622
20 years and older	03-04	**3.77** (3.24-4.38)	**3.30** (2.90-4.00)	**7.40** (6.20-9.00)	**18.3** (15.0-22.2)	**36.6** (23.2-59.2)	1418
Gender							
Males	03-04	**4.16** (3.55-4.86)	**3.80** (3.10-4.50)	**8.50** (7.50-9.90)	**18.5** (14.9-25.1)	**44.1** (21.9-61.5)	994
Females	03-04	**3.72** (3.15-4.40)	**3.30** (2.80-4.10)	**7.10** (6.00-8.00)	**18.4** (14.4-23.1)	**33.3** (23.3-46.0)	1046
Race/ethnicity							
Mexican Americans	03-04	**4.58** (4.03-5.22)	**4.30** (3.80-5.20)	**8.10** (6.80-9.10)	**14.9** (11.4-20.3)	**26.7** (20.3-36.2)	488
Non-Hispanic blacks	03-04	**4.72** (4.01-5.55)	**4.30** (3.30-5.20)	**9.50** (7.80-10.9)	**24.1** (16.6-34.3)	**41.3** (26.0-79.2)	503
Non-Hispanic whites	03-04	**3.78** (3.17-4.51)	**3.30** (2.90-4.10)	**7.70** (6.20-9.70)	**18.6** (14.5-23.3)	**40.5** (22.6-59.2)	921

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.4.

Serum 2,2',4,4',5,5'-Hexabromodiphenyl ether (BDE 153) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**5.69** (5.11-6.34)	**4.80** (4.20-5.30)	**11.3** (9.90-12.8)	**32.6** (27.9-40.3)	**65.7** (54.9-88.4)	2039
Age group							
12-19 years	03-04	**8.05** (6.68-9.70)	**7.50** (6.10-9.90)	**15.3** (11.7-19.4)	**31.0** (22.9-44.2)	**52.9** (35.9-68.5)	621
20 years and older	03-04	**5.41** (4.83-6.05)	**4.40** (3.80-5.10)	**10.6** (9.00-12.3)	**32.8** (26.5-45.9)	**73.3** (58.2-90.4)	1418
Gender							
Males	03-04	**6.85** (5.99-7.84)	**5.50** (4.80-6.70)	**12.7** (11.2-16.5)	**49.3** (31.0-62.9)	**88.4** (63.4-115)	994
Females	03-04	**4.78** (4.20-5.43)	**4.10** (3.40-5.00)	**9.70** (7.40-11.9)	**26.0** (20.2-31.6)	**54.5** (34.6-62.9)	1045
Race/ethnicity							
Mexican Americans	03-04	**5.11** (4.32-6.06)	**4.80** (4.20-5.40)	**8.70** (6.50-11.0)	**17.2** (13.0-25.3)	**34.0** (18.3-55.1)	487
Non-Hispanic blacks	03-04	**6.05** (5.35-6.83)	**5.50** (4.80-6.20)	**12.9** (9.90-17.5)	**30.0** (21.0-44.2)	**53.1** (36.8-63.3)	503
Non-Hispanic whites	03-04	**5.85** (5.03-6.81)	**4.90** (3.90-5.70)	**11.9** (9.90-15.2)	**39.0** (28.5-54.9)	**75.9** (58.0-93.2)	921

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 2.2.

Serum 2,2',4,4',5,6'-Hexabromodiphenyl ether (BDE 154) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	**.900** (.800-1.10)	**2.10** (1.70-2.70)	**4.20** (2.80-5.40)	2014
Age group							
12-19 years	03-04	*	< LOD	**1.20** (1.00-1.40)	**2.70** (2.00-3.00)	**4.00** (3.00-4.80)	614
20 years and older	03-04	*	< LOD	**.900** (.800-1.10)	**2.00** (1.60-2.60)	**4.20** (2.70-5.70)	1400
Gender							
Males	03-04	*	< LOD	**1.00** (.800-1.20)	**2.30** (1.80-3.00)	**4.30** (3.20-6.50)	976
Females	03-04	*	< LOD	**.900** (.800-1.00)	**1.80** (1.40-2.80)	**4.20** (2.50-5.70)	1038
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	**1.00** (.900-1.10)	**1.80** (1.40-2.30)	**3.90** (2.30-4.50)	477
Non-Hispanic blacks	03-04	*	< LOD	**1.20** (.900-1.40)	**2.70** (2.30-4.40)	**5.30** (3.10-8.70)	498
Non-Hispanic whites	03-04	*	< LOD	**.900** (.800-1.10)	**2.00** (1.50-2.80)	**4.20** (2.50-6.70)	913

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.8.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5',6-Heptabromodiphenyl ether (BDE 183) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1993
Age group							
12-19 years	03-04	*	< LOD	< LOD	< LOD	< LOD	604
20 years and older	03-04	*	< LOD	< LOD	< LOD	< LOD	1389
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	**1.70** (<LOD-2.60)	962
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	1031
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	484
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	**1.80** (<LOD-2.70)	482
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	901

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 1.7.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',5,5'-Hexabromobiphenyl (BB 153) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**2.29** (1.82-2.87)	**2.20** (2.00-2.60)	**4.40** (3.40-6.30)	**12.8** (6.60-25.5)	**27.2** (11.7-60.9)	2032
Age group							
12-19 years	03-04	*	**< LOD**	**1.10** (.900-1.60)	**2.70** (2.00-3.00)	**4.10** (2.90-4.70)	616
20 years and older	03-04	**2.72** (2.14-3.47)	**2.50** (2.20-2.80)	**4.90** (3.60-7.90)	**13.6** (7.20-34.6)	**34.6** (12.8-66.8)	1416
Gender							
Males	03-04	**2.76** (2.21-3.45)	**2.70** (2.30-3.20)	**5.40** (3.90-8.50)	**15.8** (9.30-27.8)	**35.4** (13.5-70.3)	987
Females	03-04	**1.92** (1.50-2.46)	**2.00** (1.60-2.30)	**3.60** (2.80-4.90)	**9.70** (4.60-27.5)	**23.9** (7.40-56.6)	1045
Race/ethnicity							
Mexican Americans	03-04	**1.11** (.917-1.33)	**1.10** (<LOD-1.30)	**2.60** (2.00-3.00)	**6.00** (3.50-8.60)	**10.0** (6.50-15.2)	484
Non-Hispanic blacks	03-04	**2.35** (1.64-3.37)	**2.10** (1.70-2.80)	**4.80** (3.00-12.1)	**13.9** (7.00-38.2)	**29.7** (12.1-70.2)	503
Non-Hispanic whites	03-04	**2.66** (2.06-3.42)	**2.50** (2.20-2.80)	**4.90** (3.40-7.80)	**13.5** (6.60-36.4)	**34.6** (11.6-70.3)	917

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.8.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Non-Dioxin-Like Polychlorinated Biphenyls

(The coplanar and mono-ortho-substituted PCBs are discussed in the section titled "Dioxin-Like Chemicals: Polychlorinated Dibenzo-p-dioxins, Polychlorinated Dibenzofurans, and Coplanar and Mono-ortho-substituted Polychlorinated Biphenyls.")

General Information

Polychlorinated biphenyls (PCBs) are a class of chlorinated aromatic hydrocarbon chemicals that once were used as heat-exchanger, transformer, and hydraulic fluids, and as additives to paints, oils, joint caulking, and floor tiles. Peak production occurred in the early 1970s, and production was banned in the United States after 1979. More than 1.5 billion pounds of PCBs were manufactured in the United States prior to 1977. The continued concern about these chemicals is because of their persistence in the environment and accumulation in wildlife and the animal food chain.

Food is the main source of exposure for the general population. PCBs enter the food chain by a variety of routes, including migration into food from external sources, contamination of animal feeds, and accumulation in the fatty tissues of animals. PCBs are found at higher concentrations in fatty foods (e.g., dairy products and fish). The transfer of PCBs from mother to infant via breast milk is another important source of exposure. The lesser-chlorinated PCBs are more volatile and indoor inhalational exposure from buildings containing caulking made with these PCBs prior to 1979 can increase background serum levels (Johansson et al., 2003; Kohler et al., 2005). Other sources of exposure in the general population include the release of these chemicals from PCB-containing waste sites and from fires involving transformers and capacitors. Additionally, the heat from fires can result in the production of polychlorinated dibenzofurans from PCBs. In certain

Non-Dioxin-like Polychlorinated Biphenyls in this *Report*

Non-dioxin-like polychlorinated biphenyls (IUPAC number)	CAS number
Polychlorinated biphenyls (general class)	1336-36-3
2,4,4'-Trichlorobiphenyl (PCB 28)	7012-37-5
2,2',3,5'-Tetrachlorobiphenyl (PCB 44)	41464-39-5
2,2',4,5'-Tetrachlorobiphenyl (PCB 49)	41464-40-8
2,2',5,5'-Tetrachlorobiphenyl (PCB 52)	35693-99-3
2,3',4,4'-Tetrachlorobiphenyl (PCB 66)	32598-10-0
2,4,4',5-Tetrachlorobiphenyl (PCB 74)	32690-93-0
2,2',3,4,5'-Pentachlorobiphenyl (PCB 87)	38380-02-8
2,2',4,4',5-Pentachlorobiphenyl (PCB 99)	38380-01-7
2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	37680-73-2
2,3,3',4',6-Pentachlorobiphenyl (PCB 110)	38380-03-9
2,2',3,3',4,4'-Hexachlorobiphenyl (PCB 128)	38380-07-3
2,2',3,4,4',5'-Hexachlorobiphenyl (PCB 138)	35065-28-2
2,3,3',4,4',6-Hexachlorobiphenyl (PCB 158)	74472-42-7
2,2',3,4',5,5'-Hexachlorobiphenyl (PCB 146)	51908-16-8
2,2',3,4',5',6-Hexachlorobiphenyl (PCB 149)	38380-04-0
2,2',3,5,5',6-Hexachlorobiphenyl (PCB 151)	52663-63-5
2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153)	35065-27-1
2,2',3,3',4,4',5-Heptachlorobiphenyl (PCB 170)	35065-30-6
2,2',3,3',4,5,5'-Heptachlorobiphenyl (PCB 172)	52663-74-8
2,2',3,3',4,5',6'-Heptachlorobiphenyl (PCB 177)	52663-70-4
2,2',3,3',5,5',6-Heptachlorobiphenyl (PCB 178)	52663-67-9
2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	35065-29-3
2,2',3,4,4',5',6-Heptachlorobiphenyl (PCB 183)	52663-69-1
2,2',3,4',5,5',6-Heptachlorobiphenyl (PCB 187)	52663-68-0
2,2',3,3',4,4',5,5'-Octachlorobiphenyl (PCB 194)	35694-08-7
2,2',3,3',4,4',5,6-Octachlorobiphenyl (PCB 195)	52663-78-2
2,2',3,3',4,4',5,6'-Octachlorobiphenyl (PCB 196)	42740-50-1
2,2',3,3',4,5,5',6'-Octachlorobiphenyl (PCB 199)	52663-75-9
2,2',3,4,4',5,5',6-Octachlorobiphenyl (PCB 203)	52663-76-0
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (PCB 206)	40186-72-9
2,2'3,3'4,4'5,5'6,6'-Decachlorobiphenyl (PCB 209)	2051-24-3

occupational settings, workers can be exposed to PCBs such as when repairing or manufacturing transformers, capacitors, and hydraulic systems, and when remediating hazardous-waste sites. Both U.S. FDA and OSHA have developed criteria on the allowable levels of these chemicals in foods and the workplace. The U.S. EPA has also set criteria for allowable levels in water and waste materials. The international Stockholm Convention on Persistent Organic Pollutants of 2001 establishes the most stringent guidelines to date regarding elimination, restriction and unintentional production of PCBs and selected organochlorine chemicals (Porta and Zumeta, 2002).

Exposure to these chemicals nearly always occurs as mixtures rather than from individual PCBs. The different types of PCB chemicals are known as congeners, which are compounds that are distinguished by the number of chlorine atoms and their location on the biphenyl structure. PCB congeners can be divided into the coplanar, the mono-*ortho*-substituted PCBs, and other non-dioxin-like PCBs. The significance of this designation is that the coplanar and some of the mono-*ortho*-substituted PCBs have dioxin-like toxicologic effects. Structural nomenclature is available at: http://www.epa.gov/oswer/riskassessment/pdf/1340-erasc-003.pdf. The non-dioxin-like PCBs and their metabolites do not interact substantially with the aryl hydrocarbon receptor (AhR) and may act through different pathways than the dioxin-like chemicals, so their effects are not represented in the use of toxic equivalency factors (TEFs) (Carpenter, 2006). The non-dioxin-like PCBs measured in this *Report* are listed in the table.

Human health effects that have been reported after investigations of occupational and accidental exposures to high levels of PCBs include elevations of serum hepatic enzymes, dermal changes, inconsistent associations with serum lipid levels, and some types of cancer (e.g., liver, biliary) (ATSDR, 2000; Carpenter, 2006; Charles et al., 2001; Negri et al., 2003). Animal studies have demonstrated varied effects of PCBs including neurotoxicity, immune suppression, altered thyroid and reproductive function, and liver cancer (Carpenter, 2006; U.S.EPA, 2008). Effects of PCBs in humans are difficult to study due to coexposures to the dioxin-like chemicals and other organochlorine chemicals. (Also see the section titled: "Dioxin-Like Chemicals: Polychlorinated Dibenzo-*p*-dioxins, Polychlorinated Dibenzofurans, and the Coplanar and Mono-*ortho*-substituted Polychlorinated Biphenyls").

Transplacental transfer of PCBs after maternal

Serum 2,4,4'-Trichlorobiphenyl (PCB 28) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1849
	03-04	**4.90** (4.60-5.22)	**4.96** (4.65-5.26)	**6.79** (6.40-7.31)	**9.39** (8.70-10.1)	**11.3** (10.7-11.8)	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	647
	03-04	**5.02** (4.48-5.63)	**4.88** (4.26-5.48)	**7.20** (5.90-8.60)	**10.2** (8.40-11.5)	**11.7** (10.7-13.3)	590
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1202
	03-04	**4.88** (4.61-5.17)	**4.98** (4.67-5.26)	**6.78** (6.40-7.25)	**9.10** (8.70-9.87)	**11.1** (10.6-11.8)	1276
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	886
	03-04	**4.81** (4.47-5.16)	**4.86** (4.45-5.20)	**6.70** (6.07-7.50)	**9.39** (8.34-10.4)	**10.8** (10.5-11.4)	926
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	963
	03-04	**4.99** (4.66-5.35)	**5.07** (4.73-5.37)	**6.90** (6.49-7.40)	**9.37** (8.72-10.1)	**11.6** (10.7-13.1)	940
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	618
	03-04	**4.95** (4.55-5.38)	**4.90** (4.40-5.70)	**6.70** (6.07-7.90)	**8.94** (8.17-9.70)	**10.5** (9.02-14.7)	413
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	392
	03-04	**4.95** (4.20-5.84)	**5.03** (4.10-5.60)	**7.20** (5.62-8.80)	**10.2** (8.51-12.4)	**13.1** (10.8-15.3)	459
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	687
	03-04	**4.89** (4.58-5.22)	**4.90** (4.61-5.26)	**6.76** (6.33-7.32)	**9.40** (8.70-10.3)	**11.1** (10.6-11.8)	876

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00 and 03-04 are 32.4 and 1.7.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.
# Data not available for Survey years 2001-2002.

environmental exposure has been reported to be associated with altered psychomotor development in children and lower birth weight and size in newborns (Hertz-Picciotto et al., 2005; Jacobson and Jacobson, 1996; Koopman-Essenboom et al., 1996; Longnecker et al., 2003; Lundqvist et al., 2006; Sagiv et al., 2007; Sala et al., 2001), although other studies have either not confirmed these findings or found that such effects do not persist into toddler and school aged children (Gladen and Rogan, 1991; Gray et al., 2005; Hertz-Picciotto et al., 2005; Koopman-Essenboom et al., 1996; Wolff et al., 2007). Many animal studies demonstrate that high dose PCB impairs neurodevelopment or their hydroxylated metabolites may interfere with thyroid hormone-dependent neurodevelopment (Kimura-Kuroda et al., 2007; Nguon et al., 2005; Purkey et al., 2004; Roegge et al., 2006).

The non-dioxin-like PCBs weakly interact with estrogen and thyroid receptors and with transport proteins, and the hydroxylated metabolites of PCBs may be more potent mediators of these actions (Azulmozhiraja et al., 2005; DeCastro et al., 2006; Langer et al., 2005; Purkey et al., 2004; Kitamura etal., 2005; You et al., 2006). Variations in thyroid hormone levels have been associated with PCB exposures in human populations (Langer et al., 2007*a*; Meeker et al., 2007; Otake et al., 2007; Wang et al., 2005). Though only limited investigation of estrogenic or reproductive effects has occurred in women, inconsistent associations of PCB levels with altered spermatogenesis and reproductive hormone levels have been reported in environmentally exposed men (Giwercman et al., 2006; Rignell-Hydbom et al., 2005; Toft et al., 2006).

PCBs are not considered directly genotoxic. They are classified as probable human carcinogens by IARC and are classified by NTP as reasonably anticipated to be carcinogens. Early studies associated workplace PCB exposures with increased deaths from cancer of the liver, gallbladder, biliary tract, gastrointestinal tract, brain and malignant melanoma (Knerr and Schrenk, 2006). Follow up studies of these earlier investigations have shown no increase in deaths or cancers, with the exception of liver cancer (Kimbrough et al., 2003; Prince et al., 2006; Ross, 2004), though the contributions of dioxin-like chemicals or other organochlorines were unclear. Recent studies have associated PCB exposures with other cancers (De Roos et al., 2005; Engel et al., 2007; Prince et al., 2006). Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html and from the U.S. EPA at: http://www.epa.gov/iris.

Serum 2,4,4'-Trichlorobiphenyl (PCB 28) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1849
	03-04	**.030** (.028-.032)	**.030** (.028-.032)	**.041** (.039-.043)	**.057** (.055-.060)	**.067** (.063-.071)	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	647
	03-04	**.025** (.023-.028)	**.025** (.021-.028)	**.035** (.030-.042)	**.051** (.042-.061)	**.061** (.051-.070)	590
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1202
	03-04	**.031** (.029-.033)	**.031** (.029-.032)	**.042** (.040-.043)	**.058** (.055-.061)	**.067** (.063-.071)	1276
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	886
	03-04	**.030** (.028-.032)	**.030** (.027-.032)	**.041** (.037-.044)	**.056** (.051-.061)	**.065** (.061-.070)	926
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	963
	03-04	**.030** (.028-.032)	**.030** (.028-.032)	**.042** (.039-.044)	**.058** (.055-.061)	**.070** (.064-.075)	940
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	618
	03-04	**.030** (.028-.033)	**.031** (.027-.035)	**.041** (.036-.044)	**.053** (.048-.059)	**.063** (.054-.070)	413
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	392
	03-04	**.028** (.024-.033)	**.029** (.024-.033)	**.039** (.034-.047)	**.059** (.047-.070)	**.070** (.064-.082)	459
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	687
	03-04	**.030** (.028-.032)	**.030** (.028-.032)	**.041** (.039-.043)	**.058** (.055-.061)	**.068** (.062-.075)	876

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.
# Data not available for Survey years 2001-2002.

Biomonitoring Information

Measurement of serum PCBs generally reflect cumulative past exposure. Levels of non-dioxin-like PCBs in NHANES 2003-2004 are observed to be roughly similar to the previous two NHANES survey periods. Many PCBs can remain in the body for years after exposure, though some of the PCBs with fewer chlorine atoms have short residence times. The levels of individual PCB congeners in the body may vary by exposure source and by differences in pharmacokinetics, i.e., those with longer half-lives accumulate to higher levels. Adult age-related accumulations in the non-dioxin-like PCBs have been observed in many studies (Apostoli et al., 2005; Park et al., 2007; Patterson et al., 1994). Breastfeeding is a major source of PCBs, with serum levels increasing after birth in breastfed infants and then decreasing in early adolescence due to dilution as body mass increases (Barr et al., 2006). Fish consumption from the Great Lakes region contributed a twofold to tenfold increase in the mean concentrations of non-dioxin-like PCBs over referent populations (Patterson et al., 1994; Turyk et al., 2006). Arctic native Alaskans who consumed locally-caught fish, meat, and eggs had mean serum levels of total PCB that were nearly three times higher than the adult NHANES 1999-2000 subsample (Carpenter et al., 2005; CDC, 2005; Needham et al., 2005). Much higher levels due to contaminated fish intake have also been noted also in eastern Europe (Langer et al., 2007*b*).

The concentrations of the di-*ortho*-substituted PCBs are usually higher than the mono-*ortho*-substituted PCBs, which in turn are higher than the coplanar PCBs (CDC, 2005; Glynn et al., 2000; Longnecker et al., 2000; Patterson et al., 1994). The most frequently detected di-*ortho*-chlorine-substituted PCBs in population studies are 138, 153, and 180 (CDC, 2005; Heudorf et al., 2002; Patterson et al., 1994 and 2009; Turyk et al., 2006). These three congeners contributed a substantial portion of the total PCB concentration observed in pooled specimens representative of a New Zealand population (Bates et al., 2004); in a small population of Swedish men (Glynn et al., 2000), and in blood bank specimens from Canada (Longnecker et al., 2000). In the U.S representative subsample from NHANES 1999-2000, non-dioxin-like PCBs 138, 153, and 180 accounted for 65% of the measured total sum of PCBs (Needham et al., 2005) and for 78% of the total in a referent population of 311 Italian residents in 2001-2003 (Apostoli et al., 2005). Non-dioxin-like PCBs with five, six, and seven chlorines attached comprised about 80% of the total PCBs in human serum, or alternatively, PCBs 138, 153, 180, 187 and 118 composed 57% of the total PCB concentration in a small sample of South Korean residents and incineration workers (Park et al., 2007). In the sera of Yucheng victims analyzed 15 years after the rice oil contamination event (See the section “Dioxin-Like Chemicals” for further discussion.),73% of the total PCB concentration was contributed by PCBs 99, 138, 153, 156, 170, 179, and 180 (Hsu et al., 2005).

As has been shown for other organochlorines, median serum lipid-adjusted levels of PCB 153 declined by 38% from 1991 to 2001 in a small sample of Swedish men (Hagmar et al., 2006). In four biannual surveys covering the years 1996-2003, about 400 German fourth grade children were sampled each period and demonstrated a decrease of more than one-half in mean whole blood levels of PCBs 138, 153, and 180 (Link et al., 2005). Lipid adjusted levels of the non-dioxin-like PCBs seen in the U.S representative subsample from NHANES 2001-2002 are generally lower than levels in selected populations during the 1980s to 1990s (CDC, 2005; Glynn et al., 2000; Longnecker et al., 2000; Patterson et al., 1994).

In a convenience sample of 624 urban Germans aged 0-65 years conducted during 1998 (Heudorf et al., 2002), 95th percentile levels for PCBs 138, 153, and 180 were similar or up to two-fold higher than 95th percentile levels in the U.S. NHANES 1999-2000 subsample (CDC, 2005). In contrast, a representative pooled sampling of New Zealand residents in 1996-1997 demonstrated slightly lower levels than for NHANES 1999-2000 (Bates et al., 2004). In two separate Italian studies of a regional reference population and a convenience sample in 2001-2003, median serum levels of PCBs 138, 153, and 180, as well as the sum of measurable PCBs, were about fivefold higher than NHANES 1999-2000 (Apostoli et al., 2005; CDC, 2005; Needham et al., 2005; Turci et al., 2006). Mean levels of PCBs 153 and 180 in 753 adult native Americans were approximately similar to the 95th percentile for the overall adult NHANES 2001-2002 population (CDC, 2005; DeCaprio et al., 2005). In some other countries, comparable population levels are ten or more times higher than those reported for NHANES subsamples from 1999-2000 and 2001-2002 (CDC, 2005; Jursa et al.,2006; Petrik et al., 2006). In the sera of Yucheng victims analyzed at 15 years following the rice oil contamination event, mean serum lipid adjusted levels of PCBs 99, 153, 170, and 180 were several to eightfold higher than the 95th percentiles of NHANES 1999-2000 (Hsu et al., 2005).

Finding a measurable amount of one or more PCBs in serum does not mean that the levels of the PCBs cause an adverse health effect. Biomonitoring studies of serum PCBs can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of PCBs than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum 2,2'3,5'-Tetrachlorobiphenyl (PCB 44) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**2.06** (1.93-2.19)	**2.05** (1.90-2.20)	**3.03** (2.90-3.20)	**4.40** (4.10-4.86)	**5.70** (5.40-6.10)	1890
Age group							
12-19 years	03-04	**2.45** (2.22-2.70)	**2.44** (2.10-2.70)	**3.68** (3.19-4.37)	**5.78** (5.13-6.30)	**7.99** (6.20-9.10)	597
20 years and older	03-04	**2.00** (1.88-2.13)	**2.00** (1.90-2.11)	**2.97** (2.80-3.20)	**4.27** (3.85-4.70)	**5.44** (5.00-5.89)	1293
Gender							
Males	03-04	**2.12** (2.01-2.25)	**2.12** (2.00-2.30)	**3.11** (2.97-3.31)	**4.52** (4.10-5.20)	**5.89** (5.38-6.80)	942
Females	03-04	**1.99** (1.82-2.18)	**1.98** (1.80-2.20)	**2.94** (2.72-3.21)	**4.30** (3.77-5.05)	**5.60** (5.00-6.20)	948
Race/ethnicity							
Mexican Americans	03-04	**2.09** (1.88-2.31)	**2.10** (1.90-2.39)	**3.10** (2.52-3.73)	**4.20** (3.30-6.10)	**5.69** (3.80-7.40)	427
Non-Hispanic blacks	03-04	**2.21** (1.94-2.52)	**2.12** (1.80-2.56)	**3.18** (2.72-3.94)	**4.90** (3.90-6.32)	**6.32** (5.01-9.62)	464
Non-Hispanic whites	03-04	**2.03** (1.87-2.19)	**2.01** (1.90-2.20)	**3.07** (2.90-3.29)	**4.40** (4.01-4.95)	**5.70** (5.25-6.35)	877

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.

Serum 2,2'3,5'-Tetrachlorobiphenyl (PCB 44) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.013** (.012-.013)	**.013** (.012-.014)	**.018** (.017-.020)	**.026** (.024-.028)	**.032** (.030-.034)	1890
Age group							
12-19 years	03-04	**.012** (.011-.014)	**.013** (.011-.014)	**.019** (.016-.021)	**.029** (.024-.031)	**.037** (.030-.042)	597
20 years and older	03-04	**.013** (.012-.013)	**.013** (.012-.014)	**.018** (.017-.020)	**.025** (.023-.027)	**.031** (.029-.034)	1293
Gender							
Males	03-04	**.013** (.012-.014)	**.013** (.012-.014)	**.018** (.017-.020)	**.026** (.024-.028)	**.034** (.030-.038)	942
Females	03-04	**.012** (.011-.013)	**.012** (.011-.013)	**.018** (.016-.020)	**.025** (.023-.028)	**.030** (.028-.032)	948
Race/ethnicity							
Mexican Americans	03-04	**.013** (.011-.014)	**.013** (.011-.014)	**.017** (.015-.020)	**.023** (.018-.031)	**.027** (.021-.049)	427
Non-Hispanic blacks	03-04	**.013** (.011-.014)	**.012** (.010-.014)	**.018** (.015-.022)	**.026** (.021-.034)	**.035** (.026-.040)	464
Non-Hispanic whites	03-04	**.012** (.012-.014)	**.012** (.011-.014)	**.019** (.017-.020)	**.026** (.024-.028)	**.032** (.029-.035)	877

Serum 2,2',4,5'-Tetrachlorobiphenyl (PCB 49) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**1.29** (1.20-1.39)	**1.35** (1.24-1.45)	**1.90** (1.80-2.10)	**2.80** (2.60-3.08)	**3.53** (3.33-3.80)	1876
Age group							
12-19 years	03-04	**1.54** (1.37-1.72)	**1.59** (1.33-1.80)	**2.30** (2.00-2.84)	**3.60** (3.10-4.13)	**4.66** (3.80-5.73)	590
20 years and older	03-04	**1.26** (1.17-1.35)	**1.33** (1.22-1.40)	**1.90** (1.78-2.03)	**2.69** (2.50-2.80)	**3.36** (3.15-3.63)	1286
Gender							
Males	03-04	**1.36** (1.27-1.45)	**1.40** (1.30-1.50)	**2.00** (1.90-2.20)	**3.00** (2.60-3.23)	**3.79** (3.36-4.10)	932
Females	03-04	**1.23** (1.12-1.35)	**1.30** (1.13-1.40)	**1.80** (1.70-2.04)	**2.66** (2.38-3.01)	**3.39** (3.02-3.73)	944
Race/ethnicity							
Mexican Americans	03-04	**1.33** (1.20-1.48)	**1.46** (1.20-1.57)	**2.00** (1.67-2.30)	**2.70** (2.17-3.80)	**3.56** (2.63-4.20)	426
Non-Hispanic blacks	03-04	**1.40** (1.23-1.59)	**1.40** (1.20-1.64)	**2.06** (1.70-2.80)	**3.23** (2.80-3.70)	**3.88** (3.33-5.53)	453
Non-Hispanic whites	03-04	**1.26** (1.15-1.38)	**1.32** (1.20-1.40)	**1.90** (1.78-2.11)	**2.77** (2.50-3.10)	**3.45** (3.20-3.90)	876

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.4.

Serum 2,2',4,5'-Tetrachlorobiphenyl (PCB 49) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.008** (.007-.008)	**.008** (.007-.009)	**.012** (.011-.012)	**.016** (.015-.017)	**.019** (.018-.021)	1876
Age group							
12-19 years	03-04	**.008** (.007-.009)	**.008** (.007-.009)	**.012** (.010-.013)	**.018** (.015-.019)	**.022** (.018-.025)	590
20 years and older	03-04	**.008** (.007-.008)	**.008** (.007-.009)	**.012** (.011-.013)	**.015** (.015-.017)	**.019** (.018-.021)	1286
Gender							
Males	03-04	**.008** (.008-.009)	**.008** (.008-.009)	**.012** (.011-.013)	**.017** (.015-.018)	**.021** (.019-.022)	932
Females	03-04	**.007** (.007-.008)	**.008** (.007-.008)	**.011** (.010-.012)	**.015** (.014-.017)	**.018** (.017-.019)	944
Race/ethnicity							
Mexican Americans	03-04	**.008** (.007-.009)	**.008** (.007-.009)	**.011** (.010-.014)	**.015** (.012-.018)	**.018** (.015-.023)	426
Non-Hispanic blacks	03-04	**.008** (.007-.009)	**.008** (.007-.009)	**.012** (.010-.014)	**.017** (.015-.020)	**.021** (.017-.026)	453
Non-Hispanic whites	03-04	**.008** (.007-.009)	**.008** (.007-.009)	**.012** (.011-.013)	**.016** (.015-.017)	**.019** (.018-.021)	876

Serum 2,2',5,5'-Tetrachlorobiphenyl (PCB 52) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1912
	01-02	*	< LOD	< LOD	< LOD	**16.5** (14.3-17.2)	1537
	03-04	**2.66** (2.43-2.91)	**2.74** (2.50-3.00)	**4.17** (3.72-4.60)	**5.91** (5.40-6.67)	**7.60** (7.01-8.00)	1897
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	664
	01-02	*	< LOD	< LOD	**16.2** (<LOD-23.8)	**22.9** (16.9-32.3)	291
	03-04	**3.16** (2.81-3.56)	**3.22** (2.60-3.96)	**5.15** (4.46-5.79)	**7.60** (6.55-8.33)	**9.20** (7.80-12.5)	597
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1248
	01-02	*	< LOD	< LOD	< LOD	**16.0** (13.5-16.9)	1246
	03-04	**2.59** (2.36-2.84)	**2.70** (2.46-2.92)	**4.06** (3.60-4.43)	**5.70** (5.16-6.49)	**7.15** (6.62-7.80)	1300
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	908
	01-02	*	< LOD	< LOD	< LOD	**16.0** (<LOD-17.5)	716
	03-04	**2.75** (2.54-2.98)	**2.80** (2.55-3.20)	**4.36** (3.90-4.88)	**5.94** (5.51-6.80)	**7.80** (7.29-8.49)	946
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1004
	01-02	*	< LOD	< LOD	< LOD	**16.6** (14.0-18.2)	821
	03-04	**2.57** (2.30-2.87)	**2.70** (2.40-2.96)	**3.96** (3.52-4.30)	**5.86** (4.96-6.67)	**7.15** (6.57-8.10)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	< LOD	**16.9** (<LOD-20.6)	366
	03-04	**2.88** (2.56-3.24)	**3.00** (2.70-3.30)	**4.41** (3.60-5.30)	**6.00** (4.71-8.11)	**7.83** (5.70-12.0)	426
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	< LOD	< LOD	**16.6** (<LOD-20.9)	282
	03-04	**2.74** (2.35-3.19)	**2.58** (2.08-3.40)	**4.11** (3.30-5.60)	**6.92** (5.10-8.70)	**8.70** (7.10-10.2)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	716
	01-02	*	< LOD	< LOD	< LOD	**16.6** (14.7-17.5)	773
	03-04	**2.60** (2.35-2.88)	**2.70** (2.40-2.98)	**4.17** (3.70-4.60)	**5.79** (5.20-6.75)	**7.37** (6.80-7.87)	885

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 12.4, and 0.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',5,5'-Tetrachlorobiphenyl (PCB 52) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1912
	01-02	*	< LOD	< LOD	< LOD	**.090** (.080-.100)	1537
	03-04	**.016** (.015-.018)	**.017** (.015-.019)	**.024** (.022-.028)	**.035** (.032-.037)	**.043** (.039-.046)	1897
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	664
	01-02	*	< LOD	< LOD	**.080** (<LOD-.100)	**.100** (.080-.140)	291
	03-04	**.016** (.014-.018)	**.017** (.014-.019)	**.026** (.022-.029)	**.037** (.032-.041)	**.042** (.037-.056)	597
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1248
	01-02	*	< LOD	< LOD	< LOD	**.090** (.080-.090)	1246
	03-04	**.016** (.015-.018)	**.017** (.015-.019)	**.024** (.022-.028)	**.034** (.031-.036)	**.043** (.038-.045)	1300
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	908
	01-02	*	< LOD	< LOD	< LOD	**.090** (<LOD-.110)	716
	03-04	**.017** (.016-.018)	**.018** (.016-.020)	**.025** (.023-.029)	**.036** (.032-.039)	**.044** (.040-.048)	946
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1004
	01-02	*	< LOD	< LOD	< LOD	**.090** (.080-.100)	821
	03-04	**.016** (.014-.017)	**.016** (.014-.018)	**.024** (.021-.028)	**.033** (.030-.036)	**.042** (.036-.046)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	< LOD	**.090** (<LOD-.110)	366
	03-04	**.018** (.016-.020)	**.018** (.016-.021)	**.025** (.022-.030)	**.035** (.028-.044)	**.044** (.032-.064)	426
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	< LOD	< LOD	**.090** (<LOD-.110)	282
	03-04	**.016** (.014-.018)	**.015** (.012-.019)	**.022** (.019-.031)	**.035** (.029-.043)	**.043** (.035-.049)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	716
	01-02	*	< LOD	< LOD	< LOD	**.090** (.080-.100)	773
	03-04	**.016** (.014-.018)	**.017** (.014-.019)	**.024** (.022-.028)	**.035** (.032-.037)	**.043** (.038-.047)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3',4,4'-Tetrachlorobiphenyl (PCB 66) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1931
	01-02	*	< LOD	< LOD	< LOD	< LOD	2250
	03-04	**1.39** (1.32-1.47)	**1.37** (1.30-1.40)	**1.97** (1.90-2.10)	**3.10** (2.94-3.26)	**4.10** (3.90-4.55)	1898
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	671
	01-02	*	< LOD	< LOD	< LOD	< LOD	724
	03-04	**1.24** (1.14-1.34)	**1.20** (1.10-1.26)	**1.76** (1.62-2.00)	**2.40** (2.30-2.70)	**3.25** (2.70-4.10)	598
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1260
	01-02	*	< LOD	< LOD	< LOD	< LOD	1526
	03-04	**1.42** (1.34-1.49)	**1.40** (1.30-1.43)	**2.00** (1.90-2.12)	**3.10** (2.97-3.40)	**4.20** (3.90-4.71)	1300
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1047
	03-04	**1.29** (1.20-1.39)	**1.30** (1.20-1.38)	**1.87** (1.72-2.01)	**2.70** (2.50-3.00)	**3.30** (2.96-3.82)	947
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1012
	01-02	*	< LOD	< LOD	< LOD	< LOD	1203
	03-04	**1.50** (1.42-1.58)	**1.41** (1.38-1.50)	**2.10** (1.92-2.30)	**3.70** (3.20-4.00)	**5.08** (4.10-5.46)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	< LOD	< LOD	< LOD	548
	03-04	**1.19** (1.09-1.30)	**1.14** (1.00-1.30)	**1.60** (1.48-1.73)	**2.23** (1.80-3.20)	**3.20** (2.46-3.60)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	414
	01-02	*	< LOD	< LOD	< LOD	< LOD	495
	03-04	**1.50** (1.34-1.68)	**1.38** (1.21-1.50)	**2.31** (1.80-2.80)	**3.80** (3.10-4.80)	**5.46** (4.30-8.60)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	723
	01-02	*	< LOD	< LOD	< LOD	< LOD	1047
	03-04	**1.39** (1.31-1.47)	**1.39** (1.30-1.45)	**1.96** (1.90-2.10)	**3.01** (2.71-3.28)	**4.09** (3.70-4.33)	885

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 12.4, and 0.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3',4,4'-Tetrachlorobiphenyl (PCB 66) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1931
	01-02	*	< LOD	< LOD	< LOD	< LOD	2250
	03-04	**.008** (.008-.009)	**.008** (.008-.009)	**.012** (.012-.013)	**.019** (.018-.021)	**.025** (.024-.030)	1898
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	671
	01-02	*	< LOD	< LOD	< LOD	< LOD	724
	03-04	**.006** (.006-.007)	**.006** (.005-.007)	**.009** (.008-.010)	**.013** (.012-.014)	**.017** (.013-.019)	598
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1260
	01-02	*	< LOD	< LOD	< LOD	< LOD	1526
	03-04	**.009** (.008-.009)	**.008** (.008-.009)	**.013** (.012-.013)	**.020** (.019-.022)	**.026** (.024-.032)	1300
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1047
	03-04	**.008** (.007-.009)	**.008** (.007-.008)	**.011** (.010-.013)	**.017** (.016-.019)	**.020** (.019-.022)	947
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1012
	01-02	*	< LOD	< LOD	< LOD	< LOD	1203
	03-04	**.009** (.009-.010)	**.009** (.008-.009)	**.013** (.012-.014)	**.022** (.021-.024)	**.032** (.026-.034)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	< LOD	< LOD	< LOD	548
	03-04	**.007** (.007-.008)	**.007** (.006-.008)	**.010** (.009-.011)	**.015** (.011-.018)	**.018** (.014-.020)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	414
	01-02	*	< LOD	< LOD	< LOD	< LOD	495
	03-04	**.009** (.008-.009)	**.008** (.007-.009)	**.013** (.011-.015)	**.022** (.019-.030)	**.036** (.024-.070)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	723
	01-02	*	< LOD	< LOD	< LOD	< LOD	1047
	03-04	**.009** (.008-.009)	**.008** (.008-.009)	**.012** (.012-.013)	**.019** (.018-.022)	**.025** (.023-.030)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,4,4',5-Tetrachlorobiphenyl (PCB 74) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**20.8** (17.9-23.4)	**29.0** (24.5-32.3)	1924
	01-02	*	< LOD	**13.2** (11.0-15.7)	**23.5** (20.2-27.7)	**33.0** (26.9-38.7)	2307
	03-04	**4.81** (4.63-4.99)	**4.36** (3.90-4.88)	**8.72** (8.30-9.28)	**15.8** (14.7-17.7)	**22.3** (19.7-25.5)	1898
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	671
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**2.20** (2.02-2.39)	**2.20** (2.03-2.33)	**2.98** (2.80-3.30)	**4.19** (3.60-4.73)	**5.32** (4.20-6.90)	598
20 years and older	99-00	*	< LOD	**12.6** (<LOD-14.4)	**22.4** (19.5-25.6)	**30.0** (26.2-35.8)	1253
	01-02	*	< LOD	**14.7** (12.4-17.1)	**25.2** (21.4-28.9)	**34.8** (28.8-41.4)	1549
	03-04	**5.38** (5.16-5.62)	**5.00** (4.60-5.50)	**9.60** (8.90-10.6)	**17.1** (15.7-18.5)	**24.1** (20.8-27.7)	1300
Gender							
Males	99-00	*	< LOD	< LOD	**15.4** (13.0-17.8)	**21.6** (18.3-24.4)	915
	01-02	*	< LOD	**10.6** (<LOD-12.3)	**20.2** (15.4-24.9)	**28.8** (20.8-38.2)	1075
	03-04	**4.06** (3.82-4.31)	**3.62** (3.30-4.00)	**6.71** (6.20-7.77)	**12.4** (10.8-13.1)	**15.8** (14.6-18.5)	947
Females	99-00	*	< LOD	**13.9** (<LOD-16.4)	**24.6** (21.9-28.5)	**31.9** (28.8-40.3)	1009
	01-02	*	< LOD	**15.8** (13.5-18.7)	**26.1** (23.2-29.3)	**35.9** (31.4-41.4)	1232
	03-04	**5.65** (5.33-5.98)	**5.38** (4.84-5.95)	**10.9** (9.30-12.1)	**19.1** (17.4-21.1)	**27.4** (22.9-29.6)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**15.8** (12.8-18.2)	636
	01-02	*	< LOD	< LOD	**13.3** (<LOD-18.1)	**19.6** (16.2-23.0)	567
	03-04	**2.43** (2.10-2.80)	**2.12** (1.90-2.40)	**3.34** (2.90-4.16)	**6.10** (5.25-7.40)	**10.4** (6.61-12.2)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**29.0** (18.6-38.4)	**43.8** (35.4-64.0)	411
	01-02	*	< LOD	**12.0** (<LOD-14.2)	**21.7** (16.4-26.9)	**31.9** (24.5-41.0)	515
	03-04	**4.96** (4.21-5.83)	**4.00** (3.45-4.65)	**9.17** (6.80-12.4)	**23.0** (14.6-35.1)	**40.2** (23.0-68.2)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	**21.6** (18.9-24.0)	**29.0** (24.3-32.3)	719
	01-02	*	< LOD	**14.7** (12.2-17.3)	**25.8** (21.3-30.1)	**35.9** (29.0-42.5)	1061
	03-04	**5.23** (4.98-5.50)	**4.91** (4.38-5.65)	**9.30** (8.60-10.4)	**16.1** (15.1-18.2)	**21.9** (19.2-25.2)	885

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.8, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,4,4',5-Tetrachlorobiphenyl (PCB 74) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**.140** (.120-.150)	**.180** (.160-.220)	1924
	01-02	*	< LOD	**.090** (.070-.100)	**.150** (.140-.180)	**.210** (.180-.270)	2307
	03-04	**.029** (.028-.031)	**.027** (.024-.029)	**.058** (.053-.062)	**.104** (.093-.121)	**.153** (.135-.171)	1898
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	671
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.011** (.010-.012)	**.011** (.010-.012)	**.015** (.014-.018)	**.021** (.019-.025)	**.026** (.021-.033)	598
20 years and older	99-00	*	< LOD	**.080** (<LOD-.100)	**.150** (.140-.160)	**.200** (.170-.230)	1253
	01-02	*	< LOD	**.100** (.080-.110)	**.170** (.140-.190)	**.230** (.200-.280)	1549
	03-04	**.034** (.032-.035)	**.031** (.028-.033)	**.064** (.059-.068)	**.115** (.103-.128)	**.167** (.143-.186)	1300
Gender							
Males	99-00	*	< LOD	< LOD	**.100** (.090-.120)	**.150** (.130-.170)	915
	01-02	*	< LOD	**.070** (<LOD-.080)	**.130** (.100-.170)	**.190** (.140-.250)	1075
	03-04	**.025** (.023-.027)	**.023** (.021-.027)	**.043** (.040-.050)	**.077** (.067-.087)	**.103** (.092-.118)	947
Females	99-00	*	< LOD	**.100** (<LOD-.110)	**.160** (.140-.180)	**.220** (.190-.250)	1009
	01-02	*	< LOD	**.100** (.090-.110)	**.170** (.150-.190)	**.240** (.210-.290)	1232
	03-04	**.034** (.032-.037)	**.031** (.027-.036)	**.071** (.062-.085)	**.130** (.120-.143)	**.186** (.154-.216)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**.110** (.080-.130)	636
	01-02	*	< LOD	< LOD	**.090** (<LOD-.120)	**.140** (.110-.160)	567
	03-04	**.015** (.013-.017)	**.013** (.011-.016)	**.022** (.019-.026)	**.042** (.032-.054)	**.071** (.049-.097)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**.170** (.110-.250)	**.280** (.220-.420)	411
	01-02	*	< LOD	**.070** (<LOD-.080)	**.130** (.100-.170)	**.200** (.150-.250)	515
	03-04	**.028** (.024-.033)	**.022** (.019-.025)	**.055** (.038-.077)	**.153** (.090-.215)	**.236** (.143-.337)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	**.150** (.130-.160)	**.190** (.160-.210)	719
	01-02	*	< LOD	**.100** (.080-.110)	**.170** (.140-.200)	**.230** (.190-.280)	1061
	03-04	**.032** (.030-.034)	**.030** (.027-.033)	**.064** (.058-.067)	**.113** (.096-.123)	**.153** (.131-.176)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,5'-Pentachlorobiphenyl (PCB 87) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	**.656** (.579-.744)	**.900** (.800-.980)	**1.32** (1.24-1.46)	**2.02** (1.90-2.17)	**2.70** (2.40-3.03)	1892
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.706** (.629-.792)	**.860** (.800-1.00)	**1.56** (1.32-1.69)	**2.25** (2.05-2.60)	**3.44** (2.27-3.98)	596
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	**.650** (.568-.742)	**.900** (.800-.970)	**1.30** (1.22-1.40)	**2.00** (1.85-2.17)	**2.60** (2.35-2.91)	1296
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.665** (.606-.730)	**.900** (.800-.970)	**1.40** (1.30-1.50)	**2.05** (1.90-2.27)	**2.70** (2.33-3.08)	945
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	**.648** (.545-.771)	**.870** (.780-1.00)	**1.30** (1.20-1.41)	**2.00** (1.84-2.23)	**2.60** (2.35-3.08)	947
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	**.693** (.569-.843)	**.840** (.700-1.00)	**1.49** (1.14-1.70)	**2.00** (1.64-2.40)	**2.30** (2.00-3.10)	427
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.824** (.723-.939)	**1.05** (.950-1.10)	**1.70** (1.32-2.10)	**2.81** (2.48-3.09)	**3.42** (3.00-4.14)	462
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	**.625** (.531-.735)	**.830** (.780-.940)	**1.30** (1.20-1.40)	**1.97** (1.85-2.17)	**2.49** (2.30-2.80)	882

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,5'-Pentachlorobiphenyl (PCB 87) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	**.004** (.004-.005)	**.005** (.005-.006)	**.008** (.008-.009)	**.012** (.012-.013)	**.017** (.015-.017)	1892
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.004** (.003-.004)	**.005** (.004-.005)	**.008** (.007-.008)	**.011** (.010-.013)	**.016** (.011-.021)	596
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	**.004** (.004-.005)	**.006** (.005-.006)	**.008** (.008-.009)	**.012** (.011-.014)	**.017** (.014-.018)	1296
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.004** (.004-.005)	**.006** (.005-.006)	**.009** (.008-.009)	**.013** (.012-.014)	**.017** (.015-.018)	945
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	**.004** (.003-.005)	**.005** (.005-.006)	**.008** (.007-.009)	**.012** (.011-.013)	**.016** (.014-.017)	947
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	**.004** (.003-.005)	**.005** (.004-.006)	**.008** (.007-.010)	**.011** (.009-.014)	**.014** (.011-.022)	427
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.005** (.004-.005)	**.006** (.006-.006)	**.009** (.008-.012)	**.015** (.014-.017)	**.020** (.017-.027)	462
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	**.004** (.003-.005)	**.005** (.005-.006)	**.008** (.007-.009)	**.012** (.011-.013)	**.016** (.014-.017)	882

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',5-Pentachlorobiphenyl (PCB 99) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**13.1** (<LOD-14.7)	**19.1** (16.2-20.6)	1897
	01-02	*	< LOD	< LOD	**17.6** (15.3-21.0)	**26.3** (22.1-30.5)	2281
	03-04	**4.16** (3.82-4.54)	**3.79** (3.43-4.10)	**6.53** (5.76-7.56)	**13.0** (10.5-16.1)	**18.0** (16.7-19.4)	1877
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	654
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**2.34** (2.08-2.64)	**2.30** (2.05-2.60)	**3.20** (2.80-3.86)	**5.16** (3.80-6.12)	**6.00** (4.77-10.0)	587
20 years and older	99-00	*	< LOD	< LOD	**13.9** (<LOD-16.0)	**20.0** (17.2-21.6)	1243
	01-02	*	< LOD	**10.8** (<LOD-12.3)	**19.4** (16.7-22.3)	**29.0** (23.5-32.1)	1523
	03-04	**4.52** (4.14-4.94)	**4.08** (3.75-4.45)	**7.10** (6.08-8.53)	**14.7** (10.9-17.0)	**18.6** (17.1-21.3)	1290
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**16.7** (13.8-20.5)	905
	01-02	*	< LOD	< LOD	**17.0** (13.8-21.0)	**24.9** (19.8-30.1)	1061
	03-04	**3.97** (3.64-4.33)	**3.69** (3.31-4.00)	**6.11** (5.44-7.00)	**11.1** (9.40-14.3)	**16.8** (12.9-19.0)	936
Females	99-00	*	< LOD	< LOD	**13.9** (<LOD-16.2)	**20.3** (17.3-23.5)	992
	01-02	*	< LOD	< LOD	**18.0** (15.8-22.2)	**28.5** (22.5-33.2)	1220
	03-04	**4.35** (3.94-4.81)	**3.90** (3.43-4.70)	**7.05** (6.00-8.46)	**15.3** (11.5-17.3)	**18.9** (17.5-22.8)	941
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	624
	01-02	*	< LOD	< LOD	< LOD	**13.8** (10.7-17.4)	562
	03-04	**2.33** (2.08-2.62)	**2.20** (1.90-2.47)	**3.35** (2.80-4.02)	**5.21** (4.50-6.10)	**6.35** (5.53-7.55)	426
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**21.1** (17.0-31.1)	**32.0** (22.9-57.4)	400
	01-02	*	< LOD	**11.7** (10.6-13.1)	**22.5** (18.8-25.8)	**29.0** (23.0-37.2)	510
	03-04	**5.54** (4.53-6.77)	**4.81** (3.80-5.80)	**10.4** (7.20-15.3)	**23.1** (16.7-29.7)	**31.7** (24.2-49.1)	447
Non-Hispanic whites	99-00	*	< LOD	< LOD	**12.5** (<LOD-14.5)	**18.2** (14.3-20.8)	715
	01-02	*	< LOD	< LOD	**18.5** (15.3-22.3)	**28.5** (22.1-32.4)	1046
	03-04	**4.23** (3.80-4.72)	**3.90** (3.40-4.44)	**6.70** (5.70-8.00)	**12.6** (9.73-15.8)	**17.3** (15.5-18.1)	883

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 10.5, and 0.6, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',5-Pentachlorobiphenyl (PCB 99) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**.090** (<LOD-.100)	**.120** (.100-.150)	1897
	01-02	*	< LOD	< LOD	**.120** (.100-.140)	**.180** (.150-.210)	2281
	03-04	**.025** (.023-.028)	**.024** (.021-.026)	**.042** (.038-.049)	**.082** (.067-.102)	**.119** (.102-.140)	1877
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	654
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.012** (.011-.013)	**.012** (.010-.013)	**.017** (.015-.019)	**.025** (.019-.032)	**.032** (.025-.045)	587
20 years and older	99-00	*	< LOD	< LOD	**.090** (<LOD-.100)	**.130** (.110-.150)	1243
	01-02	*	< LOD	**.070** (<LOD-.080)	**.130** (.110-.160)	**.190** (.160-.210)	1523
	03-04	**.028** (.026-.031)	**.026** (.024-.028)	**.046** (.041-.054)	**.093** (.073-.110)	**.127** (.110-.153)	1290
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**.110** (.090-.130)	905
	01-02	*	< LOD	< LOD	**.110** (.090-.140)	**.160** (.120-.200)	1061
	03-04	**.025** (.022-.027)	**.023** (.021-.025)	**.040** (.036-.045)	**.070** (.059-.090)	**.110** (.078-.132)	936
Females	99-00	*	< LOD	< LOD	**.100** (<LOD-.110)	**.130** (.100-.170)	992
	01-02	*	< LOD	< LOD	**.130** (.110-.160)	**.200** (.160-.210)	1220
	03-04	**.026** (.024-.029)	**.024** (.020-.028)	**.045** (.040-.053)	**.095** (.078-.111)	**.130** (.110-.158)	941
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	624
	01-02	*	< LOD	< LOD	< LOD	**.100** (.070-.120)	562
	03-04	**.014** (.012-.016)	**.013** (.011-.016)	**.022** (.019-.026)	**.036** (.030-.040)	**.046** (.036-.058)	426
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**.140** (.110-.180)	**.210** (.150-.400)	400
	01-02	*	< LOD	**.070** (.060-.090)	**.140** (.110-.150)	**.190** (.140-.230)	510
	03-04	**.032** (.026-.039)	**.027** (.023-.033)	**.060** (.042-.086)	**.149** (.112-.172)	**.211** (.150-.306)	447
Non-Hispanic whites	99-00	*	< LOD	< LOD	**.090** (<LOD-.100)	**.110** (.090-.150)	715
	01-02	*	< LOD	< LOD	**.120** (.100-.160)	**.190** (.160-.210)	1046
	03-04	**.026** (.023-.029)	**.025** (.022-.027)	**.043** (.038-.051)	**.081** (.065-.102)	**.112** (.098-.127)	883

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,5,5'-Pentachlorobiphenyl (PCB 101) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1929
	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	**1.65** (1.51-1.81)	**1.70** (1.50-1.80)	**2.70** (2.50-2.94)	**4.40** (3.97-4.82)	**5.83** (5.29-6.66)	1897
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	669
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**1.93** (1.76-2.11)	**1.73** (1.51-2.10)	**3.20** (3.00-3.60)	**5.05** (4.23-5.87)	**7.25** (5.10-8.30)	598
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1260
	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**1.62** (1.46-1.78)	**1.67** (1.50-1.80)	**2.64** (2.40-2.90)	**4.40** (3.88-4.75)	**5.51** (5.00-6.60)	1299
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	918
	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	**1.71** (1.59-1.84)	**1.75** (1.60-1.90)	**2.80** (2.60-3.10)	**4.50** (3.97-5.06)	**6.00** (5.35-6.75)	947
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1011
	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**1.60** (1.41-1.81)	**1.61** (1.41-1.82)	**2.57** (2.30-2.98)	**4.40** (3.71-4.94)	**5.60** (4.88-7.25)	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	634
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**1.72** (1.55-1.92)	**1.70** (1.50-1.96)	**3.00** (2.30-3.80)	**4.40** (3.56-5.38)	**5.38** (4.10-6.60)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	413
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**1.69** (1.38-2.07)	**1.70** (1.50-2.16)	**3.00** (2.57-3.80)	**5.88** (3.88-7.39)	**7.68** (6.60-11.9)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	724
	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**1.61** (1.46-1.79)	**1.61** (1.41-1.80)	**2.60** (2.37-2.90)	**4.40** (3.75-4.61)	**5.50** (5.00-6.15)	885

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 25.7, 10.5, and 0.6, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,5,5'-Pentachlorobiphenyl (PCB 101) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1929
	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	**.010** (.009-.011)	**.010** (.009-.012)	**.016** (.015-.018)	**.027** (.024-.028)	**.033** (.031-.037)	1897
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	669
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.010** (.009-.011)	**.009** (.008-.011)	**.016** (.014-.018)	**.024** (.021-.028)	**.030** (.025-.044)	598
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1260
	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**.010** (.009-.011)	**.011** (.009-.012)	**.016** (.015-.018)	**.027** (.024-.029)	**.034** (.031-.037)	1299
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	918
	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	**.011** (.010-.011)	**.011** (.010-.012)	**.017** (.016-.019)	**.025** (.024-.029)	**.037** (.031-.041)	947
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1011
	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**.010** (.009-.011)	**.010** (.009-.011)	**.015** (.014-.018)	**.027** (.022-.029)	**.032** (.030-.036)	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	634
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.011** (.009-.012)	**.011** (.009-.012)	**.018** (.014-.021)	**.024** (.020-.030)	**.029** (.022-.052)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	413
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.010** (.008-.012)	**.011** (.008-.013)	**.016** (.013-.022)	**.032** (.023-.041)	**.045** (.032-.059)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	724
	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**.010** (.009-.011)	**.010** (.009-.011)	**.016** (.014-.018)	**.025** (.024-.027)	**.031** (.029-.037)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4',6-Pentachlorobiphenyl (PCB 110) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	**1.22** (1.11-1.33)	**1.20** (1.10-1.36)	**1.96** (1.80-2.20)	**3.40** (3.10-3.57)	**4.42** (3.88-4.95)	1882
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**1.44** (1.30-1.59)	**1.30** (1.20-1.50)	**2.50** (2.19-2.91)	**4.13** (3.40-4.90)	**5.40** (4.30-7.68)	593
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	**1.19** (1.08-1.30)	**1.20** (1.09-1.33)	**1.88** (1.71-2.11)	**3.30** (2.95-3.50)	**4.18** (3.66-4.94)	1289
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**1.26** (1.18-1.35)	**1.30** (1.19-1.40)	**2.05** (1.80-2.30)	**3.42** (3.07-3.70)	**4.61** (3.80-5.00)	939
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	**1.17** (1.04-1.32)	**1.20** (1.00-1.36)	**1.82** (1.70-2.20)	**3.40** (2.77-3.57)	**4.40** (3.57-5.54)	943
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	**1.33** (1.18-1.51)	**1.29** (1.13-1.50)	**2.30** (1.80-2.95)	**3.40** (2.70-4.30)	**4.10** (3.30-5.50)	420
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**1.36** (1.20-1.53)	**1.30** (1.14-1.50)	**2.10** (1.72-3.00)	**4.19** (2.91-5.10)	**5.32** (4.40-6.89)	464
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	**1.17** (1.05-1.31)	**1.20** (1.00-1.33)	**1.86** (1.70-2.16)	**3.40** (2.93-3.57)	**4.19** (3.69-4.95)	877

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.8.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4',6-Pentachlorobiphenyl (PCB 110) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	**.007** (.007-.008)	**.007** (.007-.008)	**.012** (.011-.013)	**.019** (.018-.021)	**.026** (.023-.028)	1882
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.007** (.007-.008)	**.007** (.006-.008)	**.013** (.010-.015)	**.020** (.017-.022)	**.026** (.019-.037)	593
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	**.007** (.007-.008)	**.007** (.007-.008)	**.012** (.011-.013)	**.019** (.017-.021)	**.025** (.023-.028)	1289
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.008** (.007-.008)	**.008** (.007-.009)	**.013** (.011-.014)	**.019** (.018-.021)	**.028** (.022-.031)	939
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	**.007** (.006-.008)	**.007** (.006-.008)	**.011** (.010-.013)	**.019** (.016-.022)	**.024** (.021-.027)	943
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	**.008** (.007-.009)	**.008** (.007-.010)	**.014** (.011-.016)	**.019** (.016-.022)	**.022** (.017-.043)	420
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.008** (.007-.009)	**.008** (.006-.009)	**.012** (.010-.016)	**.023** (.017-.028)	**.028** (.023-.032)	464
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	**.007** (.006-.008)	**.007** (.006-.008)	**.012** (.010-.013)	**.019** (.017-.021)	**.026** (.022-.029)	877

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4'-Hexachlorobiphenyl (PCB 128) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1927
	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	*	< LOD	< LOD	< LOD	.600 (.500-.700)	1877
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	668
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	< LOD	< LOD	.510 (<LOD-.700)	589
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1259
	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	*	< LOD	< LOD	< LOD	.620 (.490-.800)	1288
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	917
	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	*	< LOD	< LOD	< LOD	.600 (.420-.770)	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1010
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	*	< LOD	< LOD	< LOD	.630 (.500-.800)	940
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	*	< LOD	< LOD	< LOD	< LOD	424
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	*	< LOD	< LOD	.670 (.500-.800)	1.00 (.770-2.10)	455
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	725
	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	*	< LOD	< LOD	< LOD	.500 (.420-.600)	878

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4'-Hexachlorobiphenyl (PCB 128) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1927
	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	*	< LOD	< LOD	< LOD	.004 (.003-.004)	1877
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	668
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	< LOD	< LOD	.003 (<LOD-.004)	589
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1259
	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	*	< LOD	< LOD	< LOD	.004 (.004-.005)	1288
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	917
	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	*	< LOD	< LOD	< LOD	.004 (.003-.005)	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1010
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	*	< LOD	< LOD	< LOD	.004 (.003-.005)	940
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	*	< LOD	< LOD	< LOD	< LOD	424
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	*	< LOD	< LOD	.004 (.003-.005)	.006 (.005-.013)	455
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	725
	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	*	< LOD	< LOD	< LOD	.003 (.002-.004)	878

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5' and 2,3,3',4,4',6-Hexachlorobiphenyl (PCB 138 & 158) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**49.3** (42.9-55.8)	**71.2** (59.8-82.7)	1930
	01-02	**19.9** (18.0-22.0)	**20.2** (18.2-23.1)	**40.4** (35.3-45.1)	**70.1** (61.8-78.8)	**94.6** (82.5-107)	2293
	03-04	**15.1** (14.1-16.1)	**15.1** (13.6-16.6)	**30.5** (28.1-34.0)	**55.4** (47.3-63.3)	**75.3** (69.0-81.8)	1896
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	669
	01-02	*	< LOD	< LOD	**17.0** (13.7-20.2)	**23.1** (17.7-41.2)	748
	03-04	**4.97** (4.45-5.55)	**4.57** (4.10-5.02)	**7.39** (6.35-8.63)	**12.7** (10.4-14.5)	**15.2** (13.1-21.3)	598
20 years and older	99-00	*	< LOD	< LOD	**54.7** (47.4-60.8)	**72.8** (66.0-88.9)	1261
	01-02	**23.3** (21.1-25.8)	**24.0** (21.4-26.8)	**44.6** (40.4-49.2)	**73.9** (66.2-83.0)	**100** (88.8-109)	1545
	03-04	**17.7** (16.5-19.0)	**17.6** (15.5-20.4)	**34.3** (30.0-38.8)	**59.6** (50.6-66.9)	**77.4** (72.3-87.7)	1298
Gender							
Males	99-00	*	< LOD	< LOD	**47.2** (<LOD-55.7)	**68.2** (55.7-83.8)	918
	01-02	**20.1** (17.9-22.6)	**20.5** (17.6-23.5)	**39.2** (32.2-46.0)	**69.2** (58.1-82.5)	**94.6** (77.8-109)	1066
	03-04	**14.9** (13.8-15.9)	**14.4** (12.9-15.8)	**29.6** (26.6-33.8)	**56.3** (45.3-62.3)	**75.8** (63.3-87.7)	947
Females	99-00	*	< LOD	< LOD	**53.7** (44.7-61.2)	**72.1** (61.2-88.9)	1012
	01-02	**19.7** (17.8-21.7)	**20.2** (18.2-23.1)	**41.8** (37.5-45.9)	**70.1** (63.4-78.5)	**93.9** (80.2-109)	1227
	03-04	**15.3** (14.0-16.8)	**15.8** (14.2-17.8)	**31.8** (28.3-36.6)	**54.6** (47.3-64.4)	**72.5** (68.4-80.9)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	**18.6** (13.6-23.4)	**33.3** (26.5-44.2)	**51.8** (42.3-57.6)	559
	03-04	**7.06** (6.02-8.28)	**6.52** (5.20-7.60)	**12.3** (8.91-16.0)	**23.6** (18.9-28.3)	**29.2** (24.7-36.1)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**72.6** (61.7-89.4)	**122** (86.5-185)	412
	01-02	**22.3** (19.3-25.6)	**22.0** (18.4-27.1)	**46.5** (38.0-55.6)	**91.5** (70.1-112)	**122** (91.5-169)	513
	03-04	**17.8** (14.9-21.3)	**15.9** (12.5-21.0)	**41.2** (30.6-57.3)	**86.5** (69.4-110)	**153** (94.6-191)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	**49.3** (41.4-55.8)	**70.1** (55.7-85.2)	727
	01-02	**21.5** (19.2-24.0)	**22.1** (19.6-24.9)	**43.0** (37.7-48.0)	**70.7** (62.3-79.7)	**96.1** (79.1-110)	1057
	03-04	**16.0** (14.5-17.7)	**15.8** (14.6-18.4)	**31.4** (28.2-36.6)	**55.1** (47.2-62.3)	**71.6** (64.0-75.8)	883

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 41.1, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5' and 2,3,3',4,4',6-Hexachlorobiphenyl (PCB 138 & 158) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**.340** (.300-.370)	**.460** (.390-.530)	1930
	01-02	**.122** (.110-.135)	**.120** (.110-.140)	**.270** (.230-.290)	**.460** (.410-.510)	**.650** (.560-.700)	2293
	03-04	**.092** (.086-.099)	**.095** (.082-.105)	**.206** (.180-.231)	**.359** (.326-.392)	**.477** (.450-.528)	1896
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	669
	01-02	*	< LOD	< LOD	**.090** (.060-.110)	**.110** (.090-.210)	748
	03-04	**.025** (.023-.028)	**.023** (.020-.027)	**.037** (.030-.047)	**.062** (.049-.074)	**.079** (.067-.103)	598
20 years and older	99-00	*	< LOD	< LOD	**.360** (.320-.390)	**.490** (.400-.560)	1261
	01-02	**.148** (.133-.163)	**.150** (.140-.170)	**.290** (.270-.320)	**.510** (.450-.550)	**.680** (.610-.720)	1545
	03-04	**.111** (.103-.120)	**.114** (.099-.128)	**.232** (.204-.256)	**.383** (.354-.416)	**.506** (.467-.594)	1298
Gender							
Males	99-00	*	< LOD	< LOD	**.320** (<LOD-.370)	**.420** (.370-.530)	918
	01-02	**.125** (.112-.140)	**.130** (.110-.140)	**.260** (.230-.290)	**.460** (.370-.540)	**.630** (.510-.710)	1066
	03-04	**.092** (.085-.099)	**.091** (.079-.103)	**.198** (.172-.229)	**.354** (.316-.379)	**.474** (.389-.562)	947
Females	99-00	*	< LOD	< LOD	**.340** (.300-.370)	**.490** (.390-.540)	1012
	01-02	**.119** (.107-.132)	**.120** (.110-.150)	**.270** (.230-.300)	**.460** (.420-.500)	**.660** (.590-.700)	1227
	03-04	**.093** (.084-.102)	**.098** (.085-.115)	**.212** (.178-.244)	**.373** (.325-.417)	**.482** (.450-.568)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	636
	01-02	*	< LOD	**.110** (.090-.150)	**.240** (.170-.330)	**.350** (.270-.430)	559
	03-04	**.043** (.036-.051)	**.040** (.032-.049)	**.080** (.068-.100)	**.148** (.122-.203)	**.239** (.147-.346)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**.470** (.360-.670)	**.830** (.530-1.22)	412
	01-02	**.125** (.108-.146)	**.130** (.090-.160)	**.290** (.230-.350)	**.560** (.420-.680)	**.770** (.560-1.06)	513
	03-04	**.101** (.084-.122)	**.087** (.068-.113)	**.239** (.186-.326)	**.568** (.424-.811)	**.965** (.698-1.09)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	**.340** (.300-.370)	**.440** (.370-.530)	727
	01-02	**.133** (.119-.149)	**.140** (.120-.160)	**.280** (.250-.300)	**.460** (.420-.530)	**.650** (.550-.720)	1057
	03-04	**.099** (.089-.109)	**.104** (.091-.121)	**.216** (.179-.252)	**.355** (.320-.390)	**.467** (.410-.520)	883

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4',5,5'-Hexachlorobiphenyl (PCB 146) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	**13.3** (<LOD-16.1)	1923
	01-02	*	< LOD	< LOD	**11.0** (<LOD-12.5)	**15.4** (13.6-16.9)	2299
	03-04	**2.17** (2.02-2.32)	**2.21** (2.03-2.54)	**4.80** (4.38-5.21)	**8.27** (7.10-9.50)	**11.7** (10.2-13.3)	1894
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.620** (.562-.685)	**.600** (.520-.690)	**1.02** (.870-1.20)	**1.67** (1.50-1.80)	**2.30** (1.79-2.97)	594
20 years and older	99-00	*	< LOD	< LOD	< LOD	**14.3** (<LOD-17.1)	1256
	01-02	*	< LOD	< LOD	**11.8** (10.7-13.5)	**16.5** (14.6-18.1)	1541
	03-04	**2.60** (2.41-2.79)	**2.60** (2.40-2.90)	**5.27** (4.82-5.88)	**8.81** (8.00-9.80)	**12.7** (10.7-15.2)	1300
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**13.1** (<LOD-17.1)	915
	01-02	*	< LOD	< LOD	**11.0** (<LOD-13.0)	**15.4** (13.0-17.2)	1069
	03-04	**2.16** (1.97-2.37)	**2.10** (1.90-2.50)	**4.80** (4.09-5.30)	**8.30** (6.90-10.1)	**12.4** (10.0-14.9)	945
Females	99-00	*	< LOD	< LOD	< LOD	**13.9** (<LOD-16.3)	1008
	01-02	*	< LOD	< LOD	**11.0** (<LOD-12.2)	**15.2** (13.2-17.3)	1230
	03-04	**2.17** (2.02-2.34)	**2.35** (2.04-2.63)	**4.83** (4.47-5.37)	**8.00** (7.04-9.10)	**11.3** (9.95-13.2)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	633
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.940** (.826-1.07)	**.820** (.780-1.00)	**1.74** (1.21-2.60)	**3.31** (2.80-4.00)	**4.60** (3.47-6.00)	425
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**17.0** (13.4-22.9)	**29.8** (20.2-42.2)	412
	01-02	*	< LOD	< LOD	**16.6** (12.8-21.4)	**23.8** (16.9-31.6)	515
	03-04	**2.81** (2.37-3.34)	**2.60** (2.05-3.50)	**7.10** (4.97-8.90)	**16.8** (11.5-23.2)	**28.5** (17.8-41.6)	463
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	723
	01-02	*	< LOD	< LOD	**10.8** (<LOD-12.0)	**15.2** (12.8-16.8)	1054
	03-04	**2.25** (2.06-2.45)	**2.35** (2.10-2.60)	**4.82** (4.37-5.41)	**7.76** (6.94-8.70)	**10.5** (9.51-11.3)	885

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4',5,5'-Hexachlorobiphenyl (PCB 146) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	**.080** (<LOD-.110)	1923
	01-02	*	< LOD	< LOD	**.070** (<LOD-.080)	**.110** (.090-.120)	2299
	03-04	**.013** (.012-.014)	**.014** (.013-.016)	**.032** (.028-.035)	**.054** (.047-.062)	**.077** (.069-.090)	1894
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.003** (.003-.003)	**.003** (.003-.003)	**.006** (.004-.007)	**.008** (.007-.010)	**.011** (.009-.014)	594
20 years and older	99-00	*	< LOD	< LOD	< LOD	**.090** (<LOD-.120)	1256
	01-02	*	< LOD	< LOD	**.080** (.070-.090)	**.110** (.100-.120)	1541
	03-04	**.016** (.015-.018)	**.017** (.015-.020)	**.035** (.032-.038)	**.058** (.053-.064)	**.084** (.073-.099)	1300
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	**.080** (<LOD-.110)	915
	01-02	*	< LOD	< LOD	**.070** (<LOD-.090)	**.100** (.090-.120)	1069
	03-04	**.013** (.012-.015)	**.014** (.012-.016)	**.032** (.027-.036)	**.054** (.045-.063)	**.074** (.064-.096)	945
Females	99-00	*	< LOD	< LOD	< LOD	**.090** (<LOD-.110)	1008
	01-02	*	< LOD	< LOD	**.070** (<LOD-.080)	**.110** (.090-.120)	1230
	03-04	**.013** (.012-.014)	**.015** (.013-.016)	**.032** (.028-.036)	**.054** (.047-.065)	**.079** (.069-.088)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	633
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.006** (.005-.007)	**.005** (.004-.007)	**.012** (.008-.016)	**.024** (.017-.033)	**.034** (.024-.046)	425
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**.110** (.080-.130)	**.180** (.120-.270)	412
	01-02	*	< LOD	< LOD	**.100** (.080-.130)	**.150** (.110-.200)	515
	03-04	**.016** (.013-.019)	**.016** (.012-.019)	**.041** (.030-.061)	**.100** (.069-.167)	**.180** (.126-.224)	463
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	723
	01-02	*	< LOD	< LOD	**.070** (<LOD-.080)	**.100** (.090-.120)	1054
	03-04	**.014** (.013-.015)	**.015** (.013-.018)	**.033** (.028-.036)	**.053** (.047-.057)	**.069** (.064-.075)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4',5',6-Hexachlorobiphenyl (PCB 149) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	**.598** (.556-.642)	**.600** (.550-.680)	**.900** (.830-1.00)	**1.45** (1.28-1.60)	**1.90** (1.68-2.20)	1873
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.650** (.605-.698)	**.640** (.600-.700)	**1.00** (.900-1.10)	**1.70** (1.40-2.15)	**2.40** (1.80-2.98)	590
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**.590** (.546-.638)	**.600** (.540-.680)	**.900** (.800-1.00)	**1.40** (1.20-1.60)	**1.89** (1.60-2.17)	1283
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	**.623** (.578-.671)	**.650** (.600-.700)	**.960** (.880-1.06)	**1.50** (1.30-1.66)	**1.90** (1.60-2.40)	930
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**.575** (.521-.634)	**.600** (.500-.620)	**.890** (.800-.950)	**1.40** (1.20-1.67)	**1.90** (1.69-2.20)	943
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.549** (.496-.608)	**.530** (.500-.600)	**.900** (.700-1.04)	**1.28** (1.03-1.60)	**1.60** (1.26-2.30)	408
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.760** (.678-.853)	**.800** (.700-.880)	**1.20** (1.00-1.58)	**1.98** (1.70-2.59)	**2.90** (2.20-4.20)	463
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**.574** (.524-.628)	**.600** (.510-.670)	**.880** (.800-.950)	**1.33** (1.19-1.50)	**1.80** (1.50-2.02)	881

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4',5',6-Hexachlorobiphenyl (PCB 149) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	**.004** (.003-.004)	**.004** (.004-.004)	**.006** (.005-.006)	**.009** (.008-.009)	**.011** (.010-.013)	1873
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.003** (.003-.004)	**.003** (.003-.003)	**.005** (.004-.006)	**.008** (.007-.009)	**.012** (.008-.016)	590
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**.004** (.003-.004)	**.004** (.004-.004)	**.006** (.005-.006)	**.009** (.007-.010)	**.011** (.010-.013)	1283
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	**.004** (.004-.004)	**.004** (.004-.004)	**.006** (.005-.007)	**.009** (.008-.010)	**.011** (.010-.013)	930
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**.003** (.003-.004)	**.004** (.003-.004)	**.005** (.005-.006)	**.008** (.007-.010)	**.011** (.009-.013)	943
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.003** (.003-.004)	**.003** (.003-.004)	**.005** (.004-.006)	**.007** (.006-.008)	**.009** (.007-.014)	408
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.004** (.004-.005)	**.004** (.004-.005)	**.007** (.006-.008)	**.012** (.010-.013)	**.019** (.013-.022)	463
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**.004** (.003-.004)	**.004** (.003-.004)	**.005** (.005-.006)	**.008** (.007-.009)	**.010** (.009-.012)	881

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,5,5',6-Hexachlorobiphenyl (PCB 151) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	*	< LOD	.420 (.400-.500)	.700 (.640-.820)	1.00 (.840-1.30)	1870
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	.400 (<LOD-.470)	.700 (.510-.820)	.880 (.700-1.10)	588
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	*	< LOD	.440 (.400-.500)	.720 (.650-.850)	1.02 (.850-1.40)	1282
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	*	< LOD	.430 (.400-.500)	.720 (.620-.900)	1.10 (.830-1.50)	931
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	*	< LOD	.410 (.400-.500)	.700 (.600-.820)	1.00 (.830-1.20)	939
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	*	< LOD	< LOD	.500 (.400-.700)	.700 (.530-.700)	426
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	*	.400 (<LOD-.500)	.700 (.500-.900)	1.30 (.900-1.90)	2.20 (1.40-4.55)	461
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	*	< LOD	.400 (<LOD-.450)	.650 (.590-.700)	.850 (.750-1.00)	864

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,5,5',6-Hexachlorobiphenyl (PCB 151) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	*	< LOD	.003 (.002-.003)	.004 (.004-.005)	.006 (.005-.008)	1870
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	.002 (<LOD-.002)	.003 (.003-.004)	.004 (.003-.006)	588
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	*	< LOD	.003 (.003-.003)	.004 (.004-.006)	.007 (.005-.010)	1282
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	*	< LOD	.003 (.003-.003)	.005 (.004-.006)	.006 (.005-.010)	931
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	*	< LOD	.003 (.002-.003)	.004 (.004-.005)	.006 (.005-.008)	939
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	*	< LOD	< LOD	.003 (.003-.004)	.004 (.003-.005)	426
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	*	.002 (<LOD-.003)	.004 (.003-.006)	.008 (.006-.010)	.013 (.008-.028)	461
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	*	< LOD	.003 (<LOD-.003)	.004 (.004-.004)	.005 (.004-.006)	864

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**77.8** (70.2-87.3)	**114** (93.0-133)	1926
	01-02	**27.2** (24.7-30.1)	**30.1** (26.1-34.3)	**57.8** (52.1-63.2)	**94.7** (86.5-104)	**126** (109-142)	2306
	03-04	**19.8** (18.8-20.9)	**20.8** (18.4-22.2)	**43.3** (39.1-46.9)	**71.8** (64.4-82.8)	**97.1** (88.8-111)	1896
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	668
	01-02	*	< LOD	**12.5** (11.1-14.1)	**21.2** (17.4-26.7)	**31.9** (23.1-64.7)	757
	03-04	**5.86** (5.25-6.55)	**5.40** (4.70-6.21)	**8.50** (7.80-9.85)	**15.7** (12.9-18.4)	**20.7** (16.9-28.3)	596
20 years and older	99-00	*	< LOD	< LOD	**83.2** (75.9-91.8)	**122** (100-139)	1258
	01-02	**32.6** (29.5-36.1)	**35.1** (31.1-39.0)	**62.8** (57.6-68.0)	**99.5** (90.7-110)	**132** (116-146)	1549
	03-04	**23.7** (22.3-25.1)	**24.2** (21.8-27.4)	**47.1** (43.3-50.5)	**77.5** (68.0-87.9)	**101** (92.9-119)	1300
Gender							
Males	99-00	*	< LOD	< LOD	**75.0** (66.7-86.2)	**111** (87.7-128)	917
	01-02	**28.5** (25.5-32.0)	**31.5** (26.7-35.2)	**57.7** (48.3-66.2)	**97.5** (82.1-110)	**126** (104-150)	1074
	03-04	**20.0** (18.7-21.3)	**19.7** (17.7-21.2)	**42.9** (37.4-47.6)	**72.7** (60.4-88.8)	**107** (86.8-122)	947
Females	99-00	*	< LOD	< LOD	**79.0** (70.2-92.0)	**119** (91.4-142)	1009
	01-02	**26.1** (23.6-28.8)	**29.0** (25.1-33.4)	**57.9** (52.1-62.9)	**94.3** (87.8-98.2)	**128** (105-145)	1232
	03-04	**19.7** (18.4-21.1)	**21.9** (19.0-24.1)	**43.8** (39.4-47.7)	**70.9** (63.0-81.5)	**93.3** (83.8-100)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**67.5** (59.5-71.8)	634
	01-02	**12.5** (10.8-14.4)	**11.1** (<LOD-13.3)	**24.5** (18.2-33.9)	**47.4** (36.2-60.3)	**66.7** (55.2-72.3)	567
	03-04	**8.75** (7.39-10.4)	**7.86** (6.17-9.40)	**15.6** (11.4-22.2)	**30.3** (25.2-34.9)	**37.8** (31.1-45.2)	425
Non-Hispanic blacks	99-00	*	< LOD	**59.4** (<LOD-82.0)	**121** (90.3-159)	**176** (130-287)	412
	01-02	**30.0** (26.2-34.4)	**31.0** (25.8-36.4)	**65.1** (54.2-82.7)	**127** (97.1-152)	**170** (126-246)	515
	03-04	**22.8** (19.1-27.2)	**20.9** (17.0-28.7)	**54.1** (37.3-69.2)	**126** (92.9-158)	**194** (126-294)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	**76.4** (69.3-83.9)	**102** (87.8-127)	725
	01-02	**29.9** (26.8-33.4)	**33.0** (28.7-37.1)	**61.2** (55.8-66.7)	**96.3** (86.5-109)	**126** (104-142)	1061
	03-04	**21.3** (19.7-23.1)	**22.2** (20.4-25.9)	**44.9** (39.7-49.5)	**70.9** (60.4-82.1)	**91.3** (82.1-103)	885

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 55.6, 10.5, and 1.1, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**.530** (.490-.560)	**.750** (.610-.840)	1926
	01-02	**.167** (.151-.185)	**.190** (.170-.210)	**.380** (.340-.410)	**.620** (.560-.690)	**.860** (.760-.950)	2306
	03-04	**.121** (.114-.128)	**.135** (.120-.144)	**.283** (.258-.310)	**.477** (.439-.518)	**.624** (.575-.733)	1896
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	668
	01-02	*	< LOD	**.060** (.050-.070)	**.110** (.080-.140)	**.150** (.110-.310)	757
	03-04	**.030** (.027-.033)	**.027** (.025-.031)	**.044** (.039-.055)	**.076** (.062-.098)	**.101** (.079-.129)	596
20 years and older	99-00	*	< LOD	< LOD	**.560** (.510-.610)	**.790** (.670-.880)	1258
	01-02	**.206** (.187-.228)	**.220** (.200-.250)	**.410** (.380-.450)	**.670** (.600-.740)	**.900** (.820-1.04)	1549
	03-04	**.148** (.139-.158)	**.156** (.141-.179)	**.313** (.283-.339)	**.512** (.452-.563)	**.671** (.603-.756)	1300
Gender							
Males	99-00	*	< LOD	< LOD	**.530** (.470-.560)	**.690** (.580-.850)	917
	01-02	**.177** (.159-.198)	**.200** (.170-.220)	**.380** (.340-.430)	**.610** (.510-.730)	**.850** (.700-1.04)	1074
	03-04	**.123** (.115-.133)	**.127** (.111-.146)	**.277** (.253-.310)	**.474** (.413-.522)	**.608** (.533-.794)	947
Females	99-00	*	< LOD	< LOD	**.530** (.480-.590)	**.770** (.610-.880)	1009
	01-02	**.158** (.142-.175)	**.180** (.150-.210)	**.380** (.340-.400)	**.630** (.570-.710)	**.860** (.760-.950)	1232
	03-04	**.119** (.110-.128)	**.138** (.113-.149)	**.291** (.253-.319)	**.492** (.439-.541)	**.624** (.578-.689)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**.470** (.380-.540)	634
	01-02	**.075** (.063-.089)	**.060** (<LOD-.080)	**.150** (.120-.210)	**.330** (.270-.420)	**.470** (.380-.550)	567
	03-04	**.053** (.044-.064)	**.047** (.038-.057)	**.100** (.078-.144)	**.205** (.164-.241)	**.323** (.213-.435)	425
Non-Hispanic blacks	99-00	*	< LOD	**.370** (<LOD-.510)	**.750** (.620-.890)	**1.27** (.820-1.64)	412
	01-02	**.169** (.146-.195)	**.180** (.140-.200)	**.390** (.330-.490)	**.780** (.580-.950)	**1.05** (.830-1.43)	515
	03-04	**.129** (.108-.156)	**.126** (.098-.149)	**.330** (.236-.425)	**.734** (.562-1.06)	**1.26** (.892-1.60)	464
Non-Hispanic whites	99-00	*	< LOD	< LOD	**.520** (.480-.560)	**.740** (.580-.850)	725
	01-02	**.185** (.165-.207)	**.210** (.180-.230)	**.390** (.370-.430)	**.640** (.570-.720)	**.840** (.740-.990)	1061
	03-04	**.131** (.121-.143)	**.144** (.127-.170)	**.295** (.268-.329)	**.474** (.412-.518)	**.600** (.519-.689)	885

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5-Heptachlorobiphenyl (PCB 170) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**23.6** (22.0-25.4)	**30.9** (28.1-35.1)	1798
	01-02	*	< LOD	**17.5** (15.7-19.3)	**26.7** (24.9-29.0)	**35.0** (32.4-37.3)	2301
	03-04	**5.46** (5.22-5.71)	**6.30** (5.96-7.10)	**12.9** (12.3-13.9)	**21.7** (19.2-23.5)	**28.2** (25.8-29.8)	1888
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	645
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	**1.12** (.974-1.30)	**1.12** (1.00-1.30)	**1.90** (1.70-2.50)	**4.00** (3.53-4.37)	**5.60** (4.35-6.69)	592
20 years and older	99-00	*	< LOD	< LOD	**24.9** (23.3-26.4)	**33.9** (29.6-37.5)	1153
	01-02	**10.5** (<LOD-11.3)	**11.1** (<LOD-12.2)	**19.1** (17.3-20.9)	**28.4** (26.2-30.9)	**36.8** (33.4-39.4)	1545
	03-04	**6.86** (6.48-7.26)	**7.83** (6.87-8.70)	**14.2** (13.1-14.9)	**22.7** (20.7-24.9)	**29.5** (26.7-32.2)	1296
Gender							
Males	99-00	*	< LOD	< LOD	**24.1** (22.0-27.0)	**32.6** (28.1-37.0)	863
	01-02	*	**10.9** (<LOD-11.9)	**18.4** (16.3-20.9)	**28.1** (24.7-31.9)	**36.1** (32.1-38.3)	1073
	03-04	**5.81** (5.43-6.22)	**6.40** (5.61-7.68)	**13.8** (12.4-14.4)	**23.4** (20.4-25.6)	**29.4** (26.0-32.7)	942
Females	99-00	*	< LOD	< LOD	**22.4** (20.7-25.4)	**29.7** (25.8-36.3)	935
	01-02	*	< LOD	**16.4** (15.0-18.0)	**25.9** (24.0-28.4)	**34.0** (30.6-38.4)	1228
	03-04	**5.14** (4.82-5.48)	**6.28** (5.81-7.18)	**12.5** (11.5-13.8)	**19.2** (17.9-21.7)	**26.1** (24.0-29.8)	946
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**23.2** (20.3-26.5)	606
	01-02	*	< LOD	< LOD	**15.4** (11.4-18.7)	**21.1** (17.1-25.1)	565
	03-04	**2.34** (1.91-2.86)	**2.20** (1.54-3.20)	**4.91** (3.40-8.17)	**10.4** (8.40-13.5)	**13.9** (10.8-20.1)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**30.9** (23.1-36.3)	**41.9** (33.7-59.1)	382
	01-02	*	< LOD	**19.0** (14.9-23.2)	**32.5** (25.5-43.9)	**44.4** (32.5-61.7)	514
	03-04	**5.42** (4.63-6.35)	**6.28** (5.11-7.75)	**14.3** (10.7-18.3)	**31.7** (23.1-40.7)	**48.5** (32.1-66.1)	461
Non-Hispanic whites	99-00	*	< LOD	< LOD	**24.1** (22.1-25.9)	**31.0** (26.8-37.3)	658
	01-02	*	**10.9** (<LOD-12.0)	**18.4** (16.8-20.4)	**27.7** (25.4-30.2)	**35.0** (32.3-38.1)	1059
	03-04	**6.13** (5.74-6.56)	**7.40** (6.40-8.18)	**13.8** (12.6-14.6)	**21.7** (19.2-24.2)	**27.0** (24.9-29.5)	882

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 17.2, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5-Heptachlorobiphenyl (PCB 170) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**.160** (.140-.180)	**.210** (.200-.230)	1798
	01-02	*	< LOD	**.110** (.110-.120)	**.180** (.170-.200)	**.250** (.210-.270)	2301
	03-04	**.033** (.032-.035)	**.041** (.037-.045)	**.087** (.080-.092)	**.144** (.134-.149)	**.188** (.173-.202)	1888
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	645
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	**.006** (.005-.006)	**.006** (.005-.007)	**.010** (.009-.012)	**.020** (.017-.022)	**.029** (.022-.033)	592
20 years and older	99-00	*	< LOD	< LOD	**.170** (.150-.190)	**.220** (.200-.250)	1153
	01-02	**.067** (<LOD-.072)	**.070** (<LOD-.080)	**.120** (.110-.130)	**.200** (.180-.210)	**.250** (.230-.290)	1545
	03-04	**.043** (.040-.046)	**.051** (.045-.054)	**.093** (.089-.099)	**.149** (.141-.160)	**.199** (.180-.223)	1296
Gender							
Males	99-00	*	< LOD	< LOD	**.170** (.140-.200)	**.220** (.200-.250)	863
	01-02	*	**.070** (<LOD-.080)	**.120** (.110-.130)	**.190** (.170-.210)	**.250** (.210-.280)	1073
	03-04	**.036** (.033-.039)	**.043** (.036-.051)	**.089** (.080-.093)	**.148** (.132-.164)	**.200** (.173-.225)	942
Females	99-00	*	< LOD	< LOD	**.150** (.130-.170)	**.210** (.190-.230)	935
	01-02	*	< LOD	**.110** (.100-.120)	**.180** (.160-.200)	**.250** (.210-.280)	1228
	03-04	**.031** (.029-.033)	**.040** (.034-.044)	**.083** (.075-.092)	**.140** (.121-.149)	**.176** (.160-.194)	946
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**.170** (.130-.190)	606
	01-02	*	< LOD	< LOD	**.110** (.080-.130)	**.150** (.120-.190)	565
	03-04	**.014** (.012-.018)	**.015** (.010-.018)	**.032** (.025-.047)	**.073** (.054-.113)	**.119** (.078-.134)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**.190** (.150-.210)	**.260** (.190-.370)	382
	01-02	*	< LOD	**.110** (.090-.140)	**.210** (.150-.270)	**.290** (.210-.390)	514
	03-04	**.031** (.026-.037)	**.038** (.027-.044)	**.087** (.069-.117)	**.210** (.136-.280)	**.338** (.221-.380)	461
Non-Hispanic whites	99-00	*	< LOD	< LOD	**.160** (.140-.200)	**.210** (.200-.240)	658
	01-02	*	**.070** (<LOD-.080)	**.120** (.110-.130)	**.190** (.170-.210)	**.250** (.210-.280)	1059
	03-04	**.038** (.035-.041)	**.046** (.042-.052)	**.091** (.083-.096)	**.145** (.132-.151)	**.180** (.164-.207)	882

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,5,5'-Heptachlorobiphenyl (PCB 172) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1901
	01-02	*	< LOD	< LOD	< LOD	< LOD	2199
	03-04	**.647** (.606-.691)	**.900** (.800-1.00)	**1.80** (1.69-1.90)	**2.98** (2.70-3.30)	**4.16** (3.65-4.55)	1878
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
	01-02	*	< LOD	< LOD	< LOD	< LOD	679
	03-04	*	< LOD	< LOD	**.610** (.460-.840)	**1.10** (.700-1.43)	585
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1241
	01-02	*	< LOD	< LOD	< LOD	< LOD	1520
	03-04	**.805** (.746-.869)	**1.08** (1.00-1.16)	**1.95** (1.80-2.10)	**3.20** (2.87-3.60)	**4.38** (3.79-5.00)	1293
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	911
	01-02	*	< LOD	< LOD	< LOD	< LOD	1027
	03-04	**.668** (.612-.730)	**.900** (.800-1.01)	**1.82** (1.70-2.00)	**3.30** (2.80-3.80)	**4.43** (3.76-5.50)	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	990
	01-02	*	< LOD	< LOD	< LOD	< LOD	1172
	03-04	**.627** (.581-.678)	**.900** (.800-1.03)	**1.72** (1.51-1.90)	**2.80** (2.50-3.11)	**3.70** (3.37-4.26)	941
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	630
	01-02	*	< LOD	< LOD	< LOD	< LOD	519
	03-04	*	< LOD	**.700** (.470-1.20)	**1.40** (1.20-1.95)	**2.00** (1.40-2.91)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	494
	03-04	**.688** (.579-.818)	**.900** (.700-1.10)	**2.20** (1.70-2.60)	**5.00** (3.38-6.53)	**7.60** (5.00-11.3)	458
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	706
	01-02	*	< LOD	< LOD	< LOD	< LOD	1027
	03-04	**.720** (.665-.781)	**1.00** (.870-1.10)	**1.80** (1.69-2.00)	**2.94** (2.70-3.20)	**3.90** (3.53-4.20)	877

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,5,5'-Heptachlorobiphenyl (PCB 172) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1901
	01-02	*	< LOD	< LOD	< LOD	< LOD	2199
	03-04	**.004** (.004-.004)	**.006** (.005-.006)	**.012** (.011-.012)	**.021** (.019-.022)	**.027** (.024-.031)	1878
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
	01-02	*	< LOD	< LOD	< LOD	< LOD	679
	03-04	*	< LOD	< LOD	**.003** (.002-.004)	**.005** (.004-.009)	585
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1241
	01-02	*	< LOD	< LOD	< LOD	< LOD	1520
	03-04	**.005** (.005-.005)	**.007** (.006-.007)	**.013** (.012-.014)	**.022** (.020-.024)	**.028** (.025-.033)	1293
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	911
	01-02	*	< LOD	< LOD	< LOD	< LOD	1027
	03-04	**.004** (.004-.005)	**.006** (.005-.007)	**.012** (.011-.013)	**.021** (.018-.024)	**.029** (.024-.036)	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	990
	01-02	*	< LOD	< LOD	< LOD	< LOD	1172
	03-04	**.004** (.003-.004)	**.006** (.005-.006)	**.012** (.010-.012)	**.019** (.017-.021)	**.026** (.023-.028)	941
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	630
	01-02	*	< LOD	< LOD	< LOD	< LOD	519
	03-04	*	< LOD	**.005** (.003-.007)	**.010** (.007-.015)	**.017** (.011-.022)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	494
	03-04	**.004** (.003-.005)	**.006** (.004-.006)	**.013** (.010-.017)	**.030** (.020-.048)	**.052** (.028-.067)	458
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	706
	01-02	*	< LOD	< LOD	< LOD	< LOD	1027
	03-04	**.004** (.004-.005)	**.006** (.005-.007)	**.012** (.011-.013)	**.020** (.018-.022)	**.026** (.023-.029)	877

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,5',6'-Heptachlorobiphenyl (PCB 177) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1873
	01-02	*	< LOD	< LOD	< LOD	< LOD	2287
	03-04	**1.13** (1.07-1.20)	**1.30** (1.20-1.40)	**2.77** (2.50-3.09)	**5.30** (4.70-5.90)	**7.20** (6.38-8.50)	1882
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	653
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	**.600** (.500-.720)	**1.04** (.800-1.40)	**1.70** (1.20-1.95)	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1220
	01-02	*	< LOD	< LOD	< LOD	< LOD	1531
	03-04	**1.40** (1.30-1.50)	**1.50** (1.40-1.71)	**3.10** (2.80-3.44)	**5.70** (4.99-6.22)	**7.80** (6.50-9.50)	1294
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	887
	01-02	*	< LOD	< LOD	< LOD	< LOD	1065
	03-04	**1.12** (1.03-1.21)	**1.30** (1.17-1.41)	**2.70** (2.40-3.00)	**5.30** (4.72-5.80)	**7.82** (6.22-9.50)	940
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	986
	01-02	*	< LOD	< LOD	< LOD	< LOD	1222
	03-04	**1.15** (1.06-1.23)	**1.30** (1.18-1.49)	**2.80** (2.57-3.19)	**5.30** (4.50-6.06)	**6.97** (6.15-7.92)	942
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	622
	01-02	*	< LOD	< LOD	< LOD	< LOD	562
	03-04	**.500** (<LOD-.649)	**.550** (.400-.700)	**1.36** (1.00-1.63)	**2.40** (1.86-3.30)	**3.40** (2.33-4.63)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	399
	01-02	*	< LOD	< LOD	< LOD	**10.6** (<LOD-12.4)	515
	03-04	**1.52** (1.25-1.84)	**1.56** (1.29-2.05)	**4.40** (3.20-5.70)	**9.80** (6.30-13.3)	**15.8** (10.0-25.7)	458
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	698
	01-02	*	< LOD	< LOD	< LOD	< LOD	1048
	03-04	**1.16** (1.08-1.25)	**1.34** (1.20-1.50)	**2.74** (2.41-3.09)	**5.00** (4.57-5.56)	**6.50** (5.98-7.40)	880

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,5',6'-Heptachlorobiphenyl (PCB 177) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1873
	01-02	*	< LOD	< LOD	< LOD	< LOD	2287
	03-04	**.007** (.007-.007)	**.008** (.008-.009)	**.018** (.016-.021)	**.034** (.031-.037)	**.047** (.043-.056)	1882
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	653
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	< LOD	**.003** (.003-.004)	**.006** (.005-.007)	**.007** (.006-.011)	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1220
	01-02	*	< LOD	< LOD	< LOD	< LOD	1531
	03-04	**.009** (.008-.009)	**.010** (.009-.011)	**.021** (.018-.023)	**.036** (.033-.041)	**.053** (.045-.058)	1294
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	887
	01-02	*	< LOD	< LOD	< LOD	< LOD	1065
	03-04	**.007** (.006-.007)	**.009** (.008-.009)	**.018** (.016-.021)	**.032** (.030-.036)	**.045** (.039-.062)	940
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	986
	01-02	*	< LOD	< LOD	< LOD	< LOD	1222
	03-04	**.007** (.006-.008)	**.008** (.007-.009)	**.018** (.017-.021)	**.035** (.032-.042)	**.051** (.043-.056)	942
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	622
	01-02	*	< LOD	< LOD	< LOD	< LOD	562
	03-04	**.003** (<LOD-.004)	**.003** (.002-.005)	**.008** (.006-.011)	**.018** (.012-.025)	**.025** (.018-.032)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	399
	01-02	*	< LOD	< LOD	< LOD	**.070** (<LOD-.100)	515
	03-04	**.009** (.007-.011)	**.009** (.007-.012)	**.026** (.018-.036)	**.057** (.044-.090)	**.105** (.058-.143)	458
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	698
	01-02	*	< LOD	< LOD	< LOD	< LOD	1048
	03-04	**.007** (.007-.008)	**.009** (.008-.010)	**.018** (.016-.021)	**.032** (.029-.036)	**.044** (.040-.052)	880

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',5,5',6-Heptachlorobiphenyl (PCB 178) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1932
	01-02	*	< LOD	< LOD	< LOD	< LOD	2299
	03-04	**.933** (.894-.974)	**1.20** (1.10-1.30)	**2.50** (2.30-2.67)	**4.24** (3.90-4.47)	**6.10** (5.13-7.10)	1887
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	669
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	**.400** (<LOD-.480)	**.850** (.620-1.04)	**1.12** (1.00-1.32)	590
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1263
	01-02	*	< LOD	< LOD	< LOD	< LOD	1541
	03-04	**1.18** (1.11-1.25)	**1.46** (1.30-1.60)	**2.74** (2.60-2.90)	**4.41** (4.10-4.80)	**6.50** (5.69-7.58)	1297
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.991** (.918-1.07)	**1.20** (1.10-1.37)	**2.66** (2.45-2.80)	**4.50** (3.80-5.10)	**6.40** (5.30-7.70)	940
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1013
	01-02	*	< LOD	< LOD	< LOD	< LOD	1230
	03-04	**.881** (.835-.930)	**1.20** (1.10-1.30)	**2.30** (2.20-2.59)	**4.01** (3.71-4.34)	**5.40** (4.47-6.70)	947
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	635
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	*	< LOD	**.900** (.600-1.34)	**1.99** (1.37-2.60)	**3.10** (2.00-3.60)	424
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	415
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**1.09** (.911-1.30)	**1.30** (.910-1.65)	**3.10** (2.30-4.21)	**7.10** (5.13-10.1)	**11.4** (6.80-16.5)	460
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	724
	01-02	*	< LOD	< LOD	< LOD	< LOD	1054
	03-04	**1.03** (.963-1.10)	**1.30** (1.19-1.50)	**2.61** (2.40-2.80)	**4.20** (3.80-4.40)	**5.33** (4.58-6.30)	882

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',5,5',6-Heptachlorobiphenyl (PCB 178) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1932
	01-02	*	< LOD	< LOD	< LOD	< LOD	2299
	03-04	**.006** (.005-.006)	**.008** (.007-.008)	**.016** (.015-.018)	**.029** (.026-.032)	**.041** (.035-.045)	1887
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	669
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	**.002** (<LOD-.002)	**.004** (.003-.005)	**.006** (.004-.007)	590
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1263
	01-02	*	< LOD	< LOD	< LOD	< LOD	1541
	03-04	**.007** (.007-.008)	**.009** (.008-.010)	**.018** (.017-.019)	**.031** (.028-.034)	**.043** (.038-.048)	1297
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.006** (.006-.007)	**.008** (.007-.009)	**.017** (.016-.018)	**.030** (.025-.034)	**.042** (.034-.050)	940
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1013
	01-02	*	< LOD	< LOD	< LOD	< LOD	1230
	03-04	**.005** (.005-.006)	**.008** (.006-.008)	**.016** (.014-.017)	**.028** (.025-.031)	**.040** (.034-.045)	947
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	635
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	*	< LOD	**.005** (.004-.008)	**.013** (.009-.020)	**.022** (.014-.028)	424
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	415
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.006** (.005-.008)	**.008** (.006-.008)	**.019** (.016-.027)	**.044** (.032-.061)	**.077** (.045-.089)	460
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	724
	01-02	*	< LOD	< LOD	< LOD	< LOD	1054
	03-04	**.006** (.006-.007)	**.008** (.007-.010)	**.017** (.015-.018)	**.028** (.025-.031)	**.037** (.033-.045)	882

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**37.5** (32.7-41.8)	**62.0** (56.6-66.6)	**79.3** (72.1-89.2)	1924
	01-02	**19.2** (17.4-21.1)	**21.8** (19.0-24.6)	**42.2** (38.3-47.5)	**69.7** (63.7-75.9)	**87.3** (83.3-93.0)	2302
	03-04	**15.1** (14.5-15.7)	**18.0** (16.4-18.9)	**37.1** (34.9-39.5)	**63.7** (56.2-68.2)	**81.5** (75.8-89.9)	1896
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	**12.2** (<LOD-14.8)	**21.3** (14.2-26.0)	755
	03-04	**3.06** (2.65-3.54)	**2.97** (2.57-3.41)	**5.00** (4.20-5.80)	**11.1** (8.70-13.0)	**14.7** (13.0-18.8)	598
20 years and older	99-00	*	< LOD	**41.1** (37.6-45.2)	**65.6** (60.6-69.4)	**84.8** (75.6-96.1)	1257
	01-02	**23.0** (20.8-25.5)	**26.5** (22.7-28.6)	**46.7** (41.4-51.3)	**74.5** (66.7-79.8)	**91.4** (85.0-99.5)	1547
	03-04	**19.0** (17.9-20.1)	**21.5** (18.9-24.3)	**40.4** (37.9-42.8)	**66.7** (61.0-70.1)	**88.0** (77.8-96.7)	1298
Gender							
Males	99-00	*	< LOD	**40.6** (34.5-45.0)	**65.1** (58.6-71.4)	**83.8** (75.8-96.3)	919
	01-02	**21.1** (18.8-23.7)	**25.1** (21.2-30.0)	**46.7** (39.8-51.8)	**73.8** (63.2-79.8)	**86.9** (78.0-99.4)	1073
	03-04	**16.1** (14.8-17.4)	**18.5** (15.8-21.3)	**39.6** (35.8-41.7)	**68.6** (63.7-75.0)	**88.3** (76.8-96.7)	947
Females	99-00	*	< LOD	**34.4** (29.8-39.3)	**56.7** (52.2-62.6)	**74.6** (66.6-90.5)	1005
	01-02	**17.5** (15.9-19.3)	**18.5** (16.0-21.6)	**39.7** (34.8-43.9)	**64.3** (58.0-74.8)	**87.9** (79.1-98.1)	1229
	03-04	**14.2** (13.4-15.0)	**17.8** (15.8-19.2)	**35.4** (31.8-38.5)	**55.7** (51.2-59.9)	**74.3** (64.8-87.6)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**41.7** (33.2-50.5)	**57.8** (49.7-63.8)	633
	01-02	*	< LOD	**18.0** (11.5-22.7)	**36.9** (28.2-45.7)	**54.2** (42.2-60.0)	566
	03-04	**6.14** (4.91-7.67)	**5.80** (3.80-7.50)	**12.6** (8.97-21.5)	**27.2** (22.3-35.4)	**38.8** (27.2-60.7)	427
Non-Hispanic blacks	99-00	*	< LOD	**39.3** (32.2-48.4)	**78.4** (64.3-93.7)	**117** (89.6-144)	414
	01-02	**19.5** (16.5-23.1)	**21.0** (16.9-23.8)	**48.4** (36.7-57.9)	**90.5** (73.7-101)	**116** (96.1-167)	514
	03-04	**15.1** (12.8-17.7)	**18.1** (12.6-20.8)	**39.0** (29.7-51.1)	**89.9** (64.4-122)	**137** (91.4-206)	464
Non-Hispanic whites	99-00	*	< LOD	**39.9** (34.5-45.3)	**62.3** (56.5-68.6)	**79.0** (71.3-91.4)	719
	01-02	**21.4** (19.1-23.9)	**24.8** (21.5-28.1)	**45.6** (40.2-51.0)	**72.4** (63.8-78.0)	**87.9** (83.8-94.3)	1059
	03-04	**16.9** (15.9-18.0)	**19.8** (18.4-23.1)	**39.3** (35.8-42.0)	**63.7** (55.0-69.1)	**79.8** (70.1-89.3)	883

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 28.2, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**.250** (.220-.270)	**.410** (.370-.450)	**.540** (.490-.600)	1924
	01-02	**.118** (.106-.130)	**.140** (.120-.160)	**.280** (.250-.300)	**.460** (.400-.510)	**.610** (.540-.690)	2302
	03-04	**.092** (.088-.096)	**.114** (.102-.127)	**.246** (.230-.253)	**.409** (.386-.438)	**.534** (.495-.598)	1896
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	**.060** (<LOD-.080)	**.090** (.070-.140)	755
	03-04	**.016** (.014-.018)	**.015** (.013-.017)	**.025** (.022-.030)	**.050** (.046-.056)	**.076** (.056-.096)	598
20 years and older	99-00	*	< LOD	**.270** (.240-.300)	**.440** (.410-.480)	**.560** (.500-.620)	1257
	01-02	**.146** (.131-.162)	**.170** (.150-.190)	**.300** (.280-.340)	**.490** (.430-.560)	**.640** (.570-.740)	1547
	03-04	**.119** (.112-.126)	**.138** (.125-.151)	**.270** (.249-.284)	**.433** (.402-.474)	**.572** (.511-.635)	1298
Gender							
Males	99-00	*	< LOD	**.260** (.220-.300)	**.460** (.370-.510)	**.570** (.500-.650)	919
	01-02	**.131** (.117-.147)	**.170** (.140-.200)	**.300** (.260-.340)	**.480** (.410-.550)	**.620** (.530-.720)	1073
	03-04	**.099** (.091-.108)	**.117** (.098-.148)	**.250** (.231-.274)	**.422** (.388-.495)	**.596** (.499-.654)	947
Females	99-00	*	< LOD	**.230** (.200-.270)	**.380** (.340-.410)	**.510** (.430-.560)	1005
	01-02	**.106** (.096-.117)	**.120** (.100-.140)	**.260** (.230-.280)	**.420** (.380-.470)	**.610** (.520-.700)	1229
	03-04	**.085** (.080-.092)	**.110** (.094-.123)	**.230** (.209-.252)	**.386** (.349-.421)	**.494** (.459-.541)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**.280** (.200-.320)	**.390** (.320-.450)	633
	01-02	*	< LOD	**.110** (.080-.160)	**.260** (.200-.310)	**.360** (.280-.420)	566
	03-04	**.037** (.030-.047)	**.035** (.024-.051)	**.086** (.059-.118)	**.191** (.138-.313)	**.343** (.191-.405)	427
Non-Hispanic blacks	99-00	*	< LOD	**.250** (.190-.300)	**.500** (.350-.660)	**.730** (.530-1.04)	414
	01-02	**.110** (.092-.131)	**.120** (.090-.140)	**.290** (.220-.350)	**.580** (.440-.650)	**.720** (.520-1.01)	514
	03-04	**.086** (.072-.102)	**.098** (.070-.126)	**.248** (.194-.327)	**.580** (.373-.824)	**.919** (.592-1.12)	464
Non-Hispanic whites	99-00	*	< LOD	**.260** (.240-.300)	**.430** (.380-.470)	**.540** (.480-.600)	719
	01-02	**.132** (.118-.148)	**.160** (.140-.180)	**.290** (.260-.330)	**.470** (.410-.530)	**.620** (.530-.730)	1059
	03-04	**.104** (.097-.112)	**.132** (.115-.151)	**.253** (.235-.280)	**.409** (.382-.449)	**.512** (.478-.572)	883

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5',6-Heptachlorobiphenyl (PCB 183) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1928
	01-02	*	< LOD	< LOD	< LOD	< LOD	2306
	03-04	**1.45** (1.38-1.54)	**1.60** (1.50-1.77)	**3.29** (3.15-3.54)	**5.86** (5.50-6.29)	**7.90** (7.50-8.74)	1886
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	668
	01-02	*	< LOD	< LOD	< LOD	< LOD	757
	03-04	*	**.440** (<LOD-.500)	**.730** (.660-.840)	**1.30** (.990-1.62)	**1.91** (1.50-2.24)	590
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1260
	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**1.77** (1.67-1.88)	**1.88** (1.73-2.09)	**3.70** (3.34-4.00)	**6.25** (5.71-6.83)	**8.40** (7.70-9.55)	1296
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1074
	03-04	**1.47** (1.34-1.61)	**1.54** (1.40-1.77)	**3.29** (3.10-3.54)	**5.80** (5.30-6.50)	**7.90** (7.20-9.20)	940
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1009
	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**1.44** (1.34-1.55)	**1.69** (1.50-1.82)	**3.30** (3.05-3.80)	**5.88** (5.21-6.30)	**7.90** (7.31-9.24)	946
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	635
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.703** (.579-.854)	**.700** (.600-.890)	**1.40** (1.19-1.90)	**2.62** (2.20-3.47)	**3.73** (2.60-5.60)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**12.7** (<LOD-23.1)	413
	01-02	*	< LOD	< LOD	< LOD	**13.0** (<LOD-14.9)	514
	03-04	**1.64** (1.41-1.90)	**1.60** (1.20-2.00)	**4.31** (3.25-5.63)	**11.0** (6.69-13.7)	**14.8** (11.3-17.4)	459
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	722
	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**1.56** (1.43-1.69)	**1.74** (1.55-1.90)	**3.30** (3.14-3.73)	**5.71** (5.20-6.29)	**7.59** (6.70-8.04)	883

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4,4',5',6-Heptachlorobiphenyl (PCB 183) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1928
	01-02	*	< LOD	< LOD	< LOD	< LOD	2306
	03-04	**.009** (.008-.009)	**.010** (.009-.011)	**.021** (.019-.024)	**.039** (.036-.042)	**.054** (.048-.059)	1886
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	668
	01-02	*	< LOD	< LOD	< LOD	< LOD	757
	03-04	*	**.002** (<LOD-.003)	**.004** (.004-.004)	**.007** (.005-.009)	**.009** (.007-.010)	590
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1260
	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**.011** (.010-.012)	**.012** (.011-.014)	**.024** (.022-.027)	**.042** (.038-.045)	**.057** (.052-.064)	1296
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	919
	01-02	*	< LOD	< LOD	< LOD	< LOD	1074
	03-04	**.009** (.008-.010)	**.010** (.009-.011)	**.022** (.019-.025)	**.038** (.035-.042)	**.052** (.043-.064)	940
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1009
	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**.009** (.008-.009)	**.010** (.009-.012)	**.021** (.019-.023)	**.042** (.036-.044)	**.055** (.049-.061)	946
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	635
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.004** (.003-.005)	**.005** (.004-.006)	**.009** (.007-.013)	**.019** (.013-.029)	**.029** (.017-.044)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**.070** (<LOD-.150)	413
	01-02	*	< LOD	< LOD	< LOD	**.080** (<LOD-.110)	514
	03-04	**.009** (.008-.011)	**.009** (.008-.012)	**.027** (.019-.037)	**.065** (.043-.084)	**.090** (.058-.120)	459
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	722
	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**.010** (.009-.010)	**.011** (.010-.012)	**.022** (.019-.025)	**.038** (.035-.042)	**.049** (.046-.055)	883

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4',5,5',6-Heptachlorobiphenyl (PCB 187) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**17.7** (15.6-20.4)	**24.8** (22.0-27.7)	1930
	01-02	*	< LOD	**12.2** (10.6-13.8)	**21.7** (19.6-23.7)	**28.1** (26.8-29.7)	2307
	03-04	**4.23** (3.96-4.50)	**4.60** (4.20-5.23)	**10.1** (9.42-10.5)	**17.2** (16.1-18.1)	**24.3** (20.5-27.8)	1889
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**1.00** (.859-1.17)	**1.00** (.880-1.10)	**1.66** (1.50-1.99)	**3.20** (2.50-4.34)	**5.00** (3.70-6.07)	594
20 years and older	99-00	*	< LOD	< LOD	**19.3** (16.8-21.8)	**26.0** (24.1-29.0)	1263
	01-02	*	< LOD	**13.3** (12.0-15.2)	**23.0** (20.9-24.7)	**29.2** (27.3-32.0)	1549
	03-04	**5.20** (4.83-5.60)	**5.71** (5.01-6.19)	**10.9** (10.3-11.7)	**18.1** (16.9-19.5)	**25.9** (22.1-32.1)	1295
Gender							
Males	99-00	*	< LOD	< LOD	**17.8** (15.8-19.6)	**25.9** (21.6-29.8)	917
	01-02	*	< LOD	**12.7** (<LOD-15.8)	**22.5** (19.4-24.1)	**27.7** (25.2-30.3)	1075
	03-04	**4.34** (3.97-4.75)	**4.50** (4.00-5.40)	**10.4** (9.21-10.9)	**17.9** (16.1-19.5)	**25.1** (20.4-30.9)	939
Females	99-00	*	< LOD	< LOD	**17.7** (15.1-21.7)	**24.2** (21.6-27.0)	1013
	01-02	*	< LOD	**11.9** (<LOD-13.0)	**21.3** (18.5-23.5)	**28.5** (26.2-31.3)	1232
	03-04	**4.12** (3.84-4.41)	**4.67** (4.10-5.30)	**9.85** (8.83-10.5)	**16.4** (15.3-17.9)	**24.2** (19.1-27.8)	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**17.6** (15.1-19.1)	636
	01-02	*	< LOD	< LOD	**10.8** (<LOD-13.4)	**15.7** (12.7-18.2)	567
	03-04	**1.79** (1.47-2.20)	**1.58** (1.26-2.00)	**3.96** (2.70-5.90)	**7.86** (5.96-10.3)	**11.6** (9.41-14.9)	426
Non-Hispanic blacks	99-00	*	< LOD	**15.5** (<LOD-21.1)	**31.6** (26.0-39.0)	**47.1** (36.6-72.1)	412
	01-02	*	< LOD	**16.5** (12.3-21.0)	**30.3** (22.9-40.6)	**44.8** (30.3-61.9)	515
	03-04	**5.09** (4.39-5.90)	**5.40** (4.20-6.21)	**13.9** (10.6-17.7)	**31.7** (22.7-46.4)	**51.5** (31.7-76.5)	458
Non-Hispanic whites	99-00	*	< LOD	< LOD	**16.8** (14.9-18.6)	**22.0** (19.1-25.2)	727
	01-02	*	< LOD	**12.5** (10.8-14.6)	**21.7** (18.9-23.7)	**27.4** (25.2-29.5)	1061
	03-04	**4.47** (4.17-4.79)	**5.00** (4.40-5.70)	**10.1** (9.26-10.8)	**16.5** (15.3-17.9)	**21.1** (19.1-24.2)	884

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,4',5,5',6-Heptachlorobiphenyl (PCB 187) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	.120 (.110-.130)	.170 (.140-.180)	1930
	01-02	*	< LOD	.080 (.070-.090)	.140 (.130-.160)	.200 (.180-.220)	2307
	03-04	.026 (.024-.028)	.029 (.027-.032)	.065 (.061-.069)	.115 (.106-.125)	.167 (.139-.197)	1889
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	.005 (.004-.006)	.005 (.004-.006)	.009 (.007-.010)	.016 (.013-.019)	.023 (.016-.029)	594
20 years and older	99-00	*	< LOD	< LOD	.130 (.110-.140)	.180 (.160-.190)	1263
	01-02	*	< LOD	.090 (.080-.100)	.150 (.130-.180)	.210 (.190-.230)	1549
	03-04	.033 (.030-.035)	.036 (.032-.040)	.071 (.067-.075)	.124 (.112-.139)	.172 (.143-.215)	1295
Gender							
Males	99-00	*	< LOD	< LOD	.120 (.100-.140)	.180 (.140-.200)	917
	01-02	*	< LOD	.080 (<LOD-.100)	.150 (.130-.160)	.190 (.170-.230)	1075
	03-04	.027 (.024-.030)	.030 (.026-.035)	.067 (.061-.072)	.116 (.102-.137)	.160 (.137-.215)	939
Females	99-00	*	< LOD	< LOD	.120 (.110-.130)	.160 (.140-.180)	1013
	01-02	*	< LOD	.080 (<LOD-.090)	.140 (.120-.150)	.200 (.180-.220)	1232
	03-04	.025 (.023-.027)	.029 (.026-.033)	.063 (.056-.070)	.115 (.104-.125)	.168 (.141-.191)	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	.120 (.100-.130)	636
	01-02	*	< LOD	< LOD	.080 (<LOD-.100)	.100 (.090-.120)	567
	03-04	.011 (.009-.013)	.010 (.007-.015)	.025 (.018-.038)	.057 (.042-.079)	.094 (.059-.110)	426
Non-Hispanic blacks	99-00	*	< LOD	.090 (<LOD-.130)	.200 (.160-.230)	.290 (.210-.530)	412
	01-02	*	< LOD	.100 (.070-.120)	.190 (.150-.260)	.290 (.190-.380)	515
	03-04	.029 (.025-.034)	.032 (.024-.037)	.083 (.070-.109)	.191 (.140-.273)	.330 (.228-.468)	458
Non-Hispanic whites	99-00	*	< LOD	< LOD	.110 (.100-.130)	.150 (.130-.170)	727
	01-02	*	< LOD	.080 (.070-.090)	.140 (.120-.160)	.190 (.170-.220)	1061
	03-04	.028 (.026-.030)	.032 (.029-.036)	.065 (.061-.071)	.111 (.101-.124)	.153 (.132-.172)	884

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,5'-Octachlorobiphenyl (PCB 194) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	**11.1** (<LOD-11.9)	**18.2** (16.5-19.5)	**23.7** (21.0-27.0)	2279
	03-04	**2.69** (2.53-2.85)	**4.19** (3.55-4.70)	**8.47** (7.79-9.06)	**14.3** (13.3-16.0)	**19.1** (17.6-20.8)	1835
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	746
	03-04	*	< LOD	**1.11** (.700-1.57)	**2.40** (1.70-3.57)	**5.18** (2.80-6.81)	572
20 years and older	01-02	*	< LOD	**12.0** (11.0-13.3)	**19.1** (17.7-20.5)	**25.3** (22.7-28.0)	1533
	03-04	**3.64** (3.40-3.89)	**4.95** (4.56-5.42)	**9.30** (8.62-9.90)	**15.3** (13.9-17.1)	**20.1** (18.1-21.9)	1263
Gender							
Males	01-02	*	< LOD	**12.3** (10.6-14.1)	**19.2** (17.2-21.2)	**25.2** (21.7-29.0)	1059
	03-04	**2.95** (2.61-3.35)	**4.47** (3.55-5.20)	**9.60** (8.30-10.9)	**17.1** (14.2-18.8)	**21.8** (19.8-25.6)	913
Females	01-02	*	< LOD	< LOD	**17.0** (14.7-18.8)	**21.9** (19.3-26.2)	1220
	03-04	**2.45** (2.28-2.64)	**4.00** (3.39-4.49)	**7.50** (7.01-8.39)	**12.7** (11.2-13.6)	**16.6** (13.7-18.6)	922
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**14.3** (10.5-17.6)	561
	03-04	**.845** (.582-1.23)	**.900** (.640-1.49)	**2.90** (1.79-4.76)	**7.21** (4.80-8.90)	**9.50** (7.40-15.0)	410
Non-Hispanic blacks	01-02	*	< LOD	**12.3** (<LOD-15.3)	**22.6** (18.0-27.5)	**29.8** (23.7-41.1)	508
	03-04	**2.45** (1.94-3.08)	**3.62** (2.70-4.49)	**8.83** (6.80-11.2)	**18.1** (13.0-23.2)	**28.3** (18.9-35.6)	450
Non-Hispanic whites	01-02	*	< LOD	**11.9** (10.9-13.1)	**18.8** (17.1-20.2)	**24.1** (20.9-28.0)	1048
	03-04	**3.25** (2.97-3.56)	**4.90** (4.19-5.42)	**9.08** (8.36-9.80)	**14.7** (13.5-16.6)	**19.1** (17.4-21.2)	861

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,5'-Octachlorobiphenyl (PCB 194) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	**.070** (<LOD-.080)	**.120** (.110-.140)	**.160** (.150-.190)	2279
	03-04	**.016** (.015-.017)	**.026** (.022-.028)	**.056** (.052-.060)	**.096** (.091-.103)	**.129** (.116-.139)	1835
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	746
	03-04	*	< LOD	**.006** (.004-.008)	**.013** (.009-.020)	**.023** (.013-.035)	572
20 years and older	01-02	*	< LOD	**.080** (.070-.090)	**.130** (.110-.150)	**.170** (.150-.200)	1533
	03-04	**.023** (.021-.024)	**.031** (.027-.035)	**.061** (.057-.065)	**.103** (.094-.113)	**.133** (.122-.145)	1263
Gender							
Males	01-02	*	< LOD	**.080** (.070-.090)	**.140** (.110-.160)	**.170** (.150-.210)	1059
	03-04	**.018** (.016-.021)	**.027** (.023-.034)	**.061** (.054-.069)	**.106** (.095-.121)	**.142** (.129-.166)	913
Females	01-02	*	< LOD	< LOD	**.110** (.090-.130)	**.150** (.130-.180)	1220
	03-04	**.015** (.014-.016)	**.024** (.020-.027)	**.051** (.047-.056)	**.088** (.080-.096)	**.112** (.103-.117)	922
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**.100** (.080-.110)	561
	03-04	**.005** (.004-.008)	**.006** (.004-.010)	**.019** (.012-.031)	**.049** (.033-.064)	**.081** (.051-.118)	410
Non-Hispanic blacks	01-02	*	< LOD	**.080** (<LOD-.090)	**.150** (.100-.180)	**.200** (.140-.250)	508
	03-04	**.014** (.011-.018)	**.020** (.014-.026)	**.054** (.045-.063)	**.120** (.081-.155)	**.172** (.123-.202)	450
Non-Hispanic whites	01-02	*	< LOD	**.080** (.070-.090)	**.130** (.110-.150)	**.170** (.150-.190)	1048
	03-04	**.020** (.018-.022)	**.029** (.026-.034)	**.061** (.056-.066)	**.099** (.090-.106)	**.132** (.116-.143)	861

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,6-Octachlorobiphenyl (PCB 195) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2230
	03-04	*	**.900** (<LOD-1.01)	**1.98** (1.80-2.10)	**3.40** (3.10-3.60)	**4.51** (3.90-5.18)	1820
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	716
	03-04	*	< LOD	< LOD	< LOD	**1.74** (.720-3.82)	567
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1514
	03-04	**.800** (.721-.888)	**1.10** (.980-1.20)	**2.10** (2.00-2.30)	**3.53** (3.20-3.74)	**4.68** (4.12-5.19)	1253
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1035
	03-04	*	**.800** (<LOD-1.00)	**2.08** (1.82-2.20)	**3.50** (3.12-3.70)	**4.60** (3.82-5.40)	904
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1195
	03-04	*	**.970** (<LOD-1.10)	**1.85** (1.64-2.09)	**3.30** (2.86-3.60)	**4.50** (3.57-5.25)	916
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	544
	03-04	*	< LOD	< LOD	**1.80** (1.11-2.40)	**2.40** (1.80-3.50)	407
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	490
	03-04	**.709** (<LOD-.870)	**.820** (<LOD-1.14)	**2.00** (1.65-2.57)	**4.18** (3.16-5.30)	**6.90** (4.18-8.10)	444
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1037
	03-04	**.749** (<LOD-.850)	**1.00** (.800-1.18)	**2.10** (1.90-2.30)	**3.40** (3.10-3.61)	**4.44** (3.80-5.19)	856

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 28.1 and 0.7.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,6-Octachlorobiphenyl (PCB 195) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2230
	03-04	*	**.005** (<LOD-.006)	**.012** (.012-.013)	**.022** (.020-.025)	**.031** (.027-.034)	1820
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	716
	03-04	*	< LOD	< LOD	< LOD	**.007** (.004-.017)	567
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1514
	03-04	**.005** (.004-.006)	**.007** (.006-.007)	**.014** (.012-.015)	**.023** (.021-.026)	**.032** (.028-.035)	1253
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1035
	03-04	*	**.005** (<LOD-.006)	**.013** (.012-.014)	**.022** (.020-.025)	**.031** (.025-.035)	904
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1195
	03-04	*	**.006** (<LOD-.007)	**.012** (.011-.013)	**.021** (.019-.025)	**.031** (.026-.035)	916
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	544
	03-04	*	< LOD	< LOD	**.012** (.008-.018)	**.018** (.013-.025)	407
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	490
	03-04	**.004** (<LOD-.005)	**.004** (<LOD-.006)	**.012** (.010-.016)	**.027** (.019-.034)	**.041** (.029-.048)	444
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1037
	03-04	**.005** (<LOD-.005)	**.006** (.005-.007)	**.013** (.012-.014)	**.022** (.020-.025)	**.030** (.027-.033)	856

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,6' and 2,2',3,4,4',5,5',6-Octachlorobiphenyl (PCB 196 & 203) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**14.2** (13.0-15.7)	**19.2** (17.4-20.9)	2299
	03-04	**2.61** (2.44-2.79)	**3.40** (3.01-3.80)	**6.70** (6.16-7.23)	**11.8** (10.8-12.7)	**15.0** (13.2-17.4)	1878
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	755
	03-04	**.437** (<LOD-.546)	**.520** (.400-.700)	**1.10** (.900-1.42)	**2.41** (1.86-3.19)	**3.59** (2.93-4.20)	587
20 years and older	01-02	*	< LOD	< LOD	**15.0** (13.7-17.0)	**19.9** (18.2-21.4)	1544
	03-04	**3.37** (3.15-3.61)	**4.07** (3.74-4.46)	**7.30** (6.79-8.20)	**12.4** (11.5-13.2)	**15.9** (13.4-19.5)	1291
Gender							
Males	01-02	*	< LOD	< LOD	**14.6** (13.3-16.5)	**19.4** (16.3-21.2)	1071
	03-04	**2.77** (2.49-3.08)	**3.45** (3.07-3.98)	**6.92** (6.12-7.71)	**12.5** (11.2-13.7)	**16.3** (13.7-23.1)	935
Females	01-02	*	< LOD	< LOD	**13.8** (11.9-15.9)	**19.1** (17.0-21.3)	1228
	03-04	**2.46** (2.27-2.66)	**3.32** (2.83-3.80)	**6.68** (6.12-7.20)	**11.1** (9.74-12.3)	**13.4** (12.8-14.9)	943
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**11.1** (<LOD-12.5)	565
	03-04	**.947** (.689-1.30)	**1.00** (.700-1.50)	**2.80** (1.60-4.30)	**5.90** (4.30-7.40)	**8.35** (6.00-12.3)	424
Non-Hispanic blacks	01-02	*	< LOD	< LOD	**17.6** (14.2-21.0)	**23.1** (19.6-30.2)	513
	03-04	**2.45** (2.06-2.90)	**2.90** (2.33-3.80)	**7.18** (5.80-9.00)	**13.8** (11.5-16.8)	**21.6** (14.0-32.3)	453
Non-Hispanic whites	01-02	*	< LOD	< LOD	**14.7** (13.6-16.5)	**19.6** (18.1-21.3)	1058
	03-04	**3.01** (2.76-3.27)	**3.88** (3.44-4.20)	**7.10** (6.32-8.20)	**11.8** (10.8-13.1)	**15.4** (12.9-19.0)	882

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,6' and 2,2',3,4,4',5,5',6-Octachlorobiphenyl (PCB 196 & 203) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**.100** (.090-.110)	**.130** (.110-.140)	2299
	03-04	**.016** (.015-.017)	**.022** (.019-.025)	**.044** (.042-.048)	**.082** (.071-.087)	**.101** (.091-.112)	1878
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	755
	03-04	**.002** (<LOD-.003)	**.003** (.002-.004)	**.006** (.005-.007)	**.013** (.009-.016)	**.016** (.014-.025)	587
20 years and older	01-02	*	< LOD	< LOD	**.100** (.090-.110)	**.130** (.120-.150)	1544
	03-04	**.021** (.020-.023)	**.026** (.024-.028)	**.049** (.045-.052)	**.084** (.077-.090)	**.104** (.092-.123)	1291
Gender							
Males	01-02	*	< LOD	< LOD	**.100** (.090-.120)	**.130** (.110-.150)	1071
	03-04	**.017** (.015-.019)	**.023** (.020-.026)	**.045** (.042-.050)	**.084** (.077-.091)	**.106** (.093-.127)	935
Females	01-02	*	< LOD	< LOD	**.090** (.080-.100)	**.130** (.110-.140)	1228
	03-04	**.015** (.014-.016)	**.020** (.017-.023)	**.043** (.038-.047)	**.076** (.066-.084)	**.093** (.085-.111)	943
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**.070** (<LOD-.090)	565
	03-04	**.006** (.004-.008)	**.007** (.004-.010)	**.017** (.011-.026)	**.038** (.028-.054)	**.058** (.035-.087)	424
Non-Hispanic blacks	01-02	*	< LOD	< LOD	**.110** (.090-.140)	**.150** (.110-.210)	513
	03-04	**.014** (.012-.017)	**.017** (.012-.022)	**.046** (.038-.054)	**.090** (.065-.111)	**.141** (.094-.209)	453
Non-Hispanic whites	01-02	*	< LOD	< LOD	**.100** (.090-.110)	**.130** (.110-.140)	1058
	03-04	**.019** (.017-.020)	**.025** (.022-.028)	**.048** (.043-.052)	**.084** (.070-.090)	**.100** (.090-.120)	882

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,5,5',6-Octachlorobiphenyl (PCB 199) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**17.0** (15.4-18.1)	**22.4** (19.9-25.9)	2292
	03-04	**2.81** (2.64-3.00)	**3.80** (3.26-4.26)	**8.30** (7.70-9.08)	**14.9** (13.8-15.7)	**18.9** (17.9-21.3)	1861
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	**.416** (<LOD-.522)	**.500** (<LOD-.700)	**1.17** (.890-1.59)	**2.43** (2.02-2.73)	**3.92** (2.90-4.10)	579
20 years and older	01-02	*	< LOD	**10.6** (<LOD-11.8)	**17.9** (16.2-19.2)	**24.4** (20.7-27.4)	1536
	03-04	**3.71** (3.41-4.02)	**4.60** (4.10-5.08)	**9.40** (8.73-10.0)	**15.7** (14.7-16.9)	**20.6** (18.3-23.6)	1282
Gender							
Males	01-02	*	< LOD	< LOD	**17.3** (15.4-18.7)	**21.3** (19.3-24.6)	1066
	03-04	**3.01** (2.68-3.39)	**3.95** (3.30-4.67)	**9.10** (7.60-9.94)	**16.6** (14.0-17.3)	**22.1** (18.1-27.4)	925
Females	01-02	*	< LOD	< LOD	**16.2** (14.5-17.9)	**22.9** (19.4-27.3)	1226
	03-04	**2.63** (2.49-2.79)	**3.70** (3.20-4.00)	**7.70** (6.92-8.81)	**14.0** (11.6-15.3)	**17.0** (15.7-18.9)	936
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**12.3** (<LOD-14.2)	565
	03-04	**.943** (.664-1.34)	**1.00** (.600-1.50)	**3.35** (1.50-5.33)	**7.37** (5.10-10.2)	**10.2** (7.40-13.5)	418
Non-Hispanic blacks	01-02	*	< LOD	**12.5** (<LOD-15.3)	**21.9** (17.0-28.1)	**30.7** (22.4-37.4)	513
	03-04	**3.03** (2.46-3.74)	**3.60** (2.70-4.70)	**10.0** (7.70-13.7)	**21.3** (15.9-30.4)	**35.1** (21.3-43.3)	452
Non-Hispanic whites	01-02	*	< LOD	< LOD	**17.3** (15.9-18.9)	**22.7** (19.8-26.3)	1051
	03-04	**3.24** (3.03-3.47)	**4.19** (3.78-4.69)	**9.08** (7.88-9.86)	**14.8** (13.5-16.3)	**18.6** (16.9-21.7)	871

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,5,5',6-Octachlorobiphenyl (PCB 199) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**.110** (.100-.130)	**.150** (.140-.170)	2292
	03-04	**.017** (.016-.018)	**.023** (.020-.027)	**.056** (.053-.060)	**.100** (.091-.106)	**.127** (.119-.144)	1861
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	**.002** (<LOD-.003)	**.002** (<LOD-.003)	**.006** (.005-.008)	**.012** (.009-.015)	**.016** (.015-.019)	579
20 years and older	01-02	*	< LOD	**.070** (<LOD-.080)	**.120** (.110-.140)	**.160** (.140-.180)	1536
	03-04	**.023** (.021-.025)	**.029** (.026-.033)	**.062** (.058-.067)	**.106** (.097-.113)	**.135** (.120-.158)	1282
Gender							
Males	01-02	*	< LOD	< LOD	**.110** (.100-.130)	**.150** (.130-.180)	1066
	03-04	**.019** (.016-.021)	**.025** (.020-.030)	**.059** (.053-.068)	**.105** (.090-.113)	**.138** (.120-.162)	925
Females	01-02	*	< LOD	< LOD	**.110** (.100-.130)	**.150** (.130-.170)	1226
	03-04	**.016** (.015-.017)	**.022** (.019-.025)	**.054** (.047-.058)	**.094** (.085-.105)	**.120** (.108-.133)	936
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**.090** (<LOD-.110)	565
	03-04	**.006** (.004-.008)	**.007** (.004-.010)	**.019** (.011-.031)	**.051** (.029-.079)	**.079** (.051-.093)	418
Non-Hispanic blacks	01-02	*	< LOD	**.070** (<LOD-.090)	**.140** (.100-.180)	**.190** (.130-.300)	513
	03-04	**.017** (.014-.021)	**.021** (.015-.026)	**.064** (.054-.073)	**.135** (.102-.173)	**.207** (.147-.297)	452
Non-Hispanic whites	01-02	*	< LOD	< LOD	**.120** (.100-.130)	**.150** (.130-.180)	1051
	03-04	**.020** (.019-.022)	**.027** (.023-.030)	**.059** (.054-.065)	**.101** (.087-.108)	**.125** (.108-.144)	871

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (PCB 206) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2208
	03-04	**2.13** (1.97-2.31)	**2.34** (2.00-2.60)	**5.00** (4.69-5.50)	**9.20** (8.55-9.79)	**13.7** (11.5-15.6)	1867
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	723
	03-04	*	< LOD	**.900** (.750-1.20)	**1.75** (1.23-2.92)	**3.12** (1.60-6.91)	585
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1485
	03-04	**2.59** (2.37-2.83)	**2.80** (2.42-3.06)	**5.53** (5.10-6.10)	**9.61** (9.03-11.0)	**14.2** (12.2-17.1)	1282
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1033
	03-04	**2.23** (2.03-2.45)	**2.30** (1.90-2.70)	**5.10** (4.78-5.53)	**9.31** (8.18-10.8)	**13.8** (10.8-15.7)	933
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1175
	03-04	**2.05** (1.86-2.25)	**2.34** (1.95-2.78)	**5.00** (4.30-5.70)	**9.00** (8.00-9.79)	**13.6** (11.2-16.5)	934
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	533
	03-04	**.861** (<LOD-1.15)	**.730** (<LOD-1.10)	**1.70** (1.00-3.14)	**4.40** (2.61-6.20)	**6.20** (4.40-8.40)	421
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	483
	03-04	**2.27** (1.98-2.60)	**2.26** (1.85-2.51)	**5.60** (4.30-7.40)	**11.5** (9.49-16.5)	**20.9** (12.1-31.7)	456
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1034
	03-04	**2.40** (2.19-2.63)	**2.70** (2.37-3.01)	**5.37** (4.88-6.06)	**9.20** (8.65-10.1)	**13.8** (11.2-16.6)	872

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 28.1 and 0.7.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (PCB 206) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2208
	03-04	**.013** (.012-.014)	**.015** (.012-.017)	**.034** (.031-.037)	**.060** (.054-.068)	**.086** (.077-.104)	1867
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	723
	03-04	*	< LOD	**.005** (.004-.006)	**.010** (.006-.013)	**.014** (.008-.035)	585
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1485
	03-04	**.016** (.015-.018)	**.017** (.016-.020)	**.038** (.034-.042)	**.066** (.059-.074)	**.090** (.081-.112)	1282
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1033
	03-04	**.014** (.012-.015)	**.015** (.012-.018)	**.034** (.032-.038)	**.060** (.051-.070)	**.082** (.070-.097)	933
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1175
	03-04	**.012** (.011-.014)	**.014** (.012-.016)	**.035** (.029-.038)	**.061** (.054-.069)	**.088** (.078-.118)	934
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	533
	03-04	**.005** (<LOD-.007)	**.005** (<LOD-.007)	**.011** (.008-.018)	**.031** (.019-.044)	**.044** (.030-.062)	421
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	483
	03-04	**.013** (.011-.015)	**.012** (.010-.014)	**.035** (.028-.045)	**.078** (.052-.107)	**.128** (.080-.213)	456
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1034
	03-04	**.015** (.013-.016)	**.017** (.015-.020)	**.036** (.033-.040)	**.063** (.058-.069)	**.088** (.077-.107)	872

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl (PCB 209) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**1.40** (1.21-1.61)	**1.18** (1.00-1.48)	**3.20** (2.67-4.01)	**7.58** (6.20-8.81)	**11.1** (9.00-15.7)	1854
Age group							
12-19 years	03-04	*	< LOD	< LOD	**1.12** (.800-4.60)	**3.49** (1.12-6.64)	578
20 years and older	03-04	**1.63** (1.42-1.88)	**1.40** (1.18-1.70)	**3.80** (3.04-4.44)	**8.09** (6.60-9.30)	**12.3** (9.05-18.0)	1276
Gender							
Males	03-04	**1.37** (1.18-1.60)	**1.15** (1.00-1.50)	**3.00** (2.70-3.58)	**6.22** (4.97-8.20)	**9.10** (7.09-13.0)	925
Females	03-04	**1.42** (1.22-1.66)	**1.20** (1.00-1.50)	**3.46** (2.45-4.61)	**8.78** (7.45-9.47)	**13.9** (10.0-18.7)	929
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	**1.10** (.770-1.60)	**2.40** (1.60-3.60)	**3.71** (2.40-4.97)	416
Non-Hispanic blacks	03-04	**1.56** (1.37-1.78)	**1.35** (1.10-1.52)	**3.40** (2.62-4.82)	**9.83** (6.70-13.6)	**18.0** (11.8-27.7)	455
Non-Hispanic whites	03-04	**1.53** (1.31-1.79)	**1.30** (1.09-1.70)	**3.89** (3.04-4.50)	**7.95** (6.49-9.09)	**11.3** (9.07-16.3)	864

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.7.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl (PCB 209) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**.009** (.007-.010)	**.008** (.006-.009)	**.021** (.017-.026)	**.049** (.040-.058)	**.073** (.059-.097)	1854
Age group							
12-19 years	03-04	*	< LOD	< LOD	**.006** (.004-.018)	**.017** (.005-.033)	578
20 years and older	03-04	**.010** (.009-.012)	**.009** (.008-.011)	**.024** (.020-.028)	**.053** (.044-.063)	**.077** (.065-.105)	1276
Gender							
Males	03-04	**.008** (.007-.010)	**.008** (.006-.010)	**.019** (.017-.023)	**.039** (.032-.051)	**.063** (.042-.077)	925
Females	03-04	**.009** (.007-.010)	**.008** (.006-.009)	**.024** (.016-.032)	**.057** (.049-.064)	**.092** (.068-.134)	929
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	**.007** (.005-.010)	**.018** (.010-.023)	**.024** (.018-.035)	416
Non-Hispanic blacks	03-04	**.009** (.008-.010)	**.008** (.006-.009)	**.022** (.018-.027)	**.065** (.039-.077)	**.097** (.065-.144)	455
Non-Hispanic whites	03-04	**.009** (.008-.011)	**.009** (.007-.011)	**.024** (.020-.029)	**.053** (.044-.061)	**.076** (.063-.099)	864

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Dioxin-Like Chemicals: Polychlorinated Dibenzo-*p*-dioxins, Polychlorinated Dibenzofurans, and Coplanar and Mono-*ortho*-substituted Polychlorinated Biphenyls

General Information

Polychlorinated dibenzo-*p*-dioxins and dibenzofurans are two similar classes of chlorinated aromatic chemicals that are produced as contaminants or by-products. They have no known commercial or natural use. Dioxins are produced primarily during the incineration or burning of waste; the bleaching processes used in pulp and paper mills; and the chemical syntheses of trichlorophenoxyacetic acid, hexachlorophene, vinyl chloride, trichlorophenol, and pentachlorophenol. Both the synthesis and heat-related degradation of polychlorinated biphenyls (PCBs) will produce dibenzofuran byproducts. Releases from industrial sources have decreased approximately 80% since the 1980s (U.S. EPA, 2004). Today, the largest release of these chemicals occurs as a result of the open burning of household and municipal trash, landfill fires, and agricultural and forest fires. When advanced analytical techniques are used, most soil and water samples will reveal trace amounts of polychlorinated dibenzo-*p*-dioxins and dibenzofurans.

The coplanar and mono-*ortho*-substituted PCBs are chlorinated aromatic hydrocarbon chemicals that belong to the general class PCBs which were once synthesized for use as heat-exchanger, transformer, and hydraulic fluids, and also used as additives to paints, oils, window caulking, and floor tiles. Production of PCBs peaked in the early 1970s and was banned in the United States after 1979. Together

Dioxin-like Chemicals in this *Report*

Polychlorinated dibenzo-*p*-dioxins	**CAS number**
1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin (HpCDD)	35822-46-9
1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD)	39227-28-6
1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD)	57653-85-7
1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin (HxCDD)	19408-74-3
1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD)	3268-87-9
1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin (PeCDD)	40321-76-4
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)	1746-01-6
Polychlorinated dibenzofurans	**CAS number**
1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF)	67562-39-4
1,2,3,4,7,8,9-Heptachlorodibenzofuran (HpCDF)	55673-89-7
1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF)	70648-26-9
1,2,3,6,7,8-Hexachlorodibenzofuran (HxCDF)	57117-44-9
1,2,3,7,8,9-Hexachlorodibenzofuran (HxCDF)	72918-21-9
2,3,4,6,7,8-Hexchlorodibenzofuran (HxCDF)	60851-34-5
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)	39001-02-0
1,2,3,7,8-Pentachlorodibenzofuran (PeCDF)	57117-41-6
2,3,4,7,8-Pentachlorodibenzofuran (PeCDF)	57117-31-4
2,3,7,8-Tetrachlorodibenzofuran (TCDF)	51207-31-9
Coplanar polychlorinated biphenyls (IUPAC number)	**CAS number**
3,4,4',5-Tetrachlorobiphenyl (PCB 81)	70362-50-4
3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	57465-28-8
3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	32774-16-6
Mono-*ortho*-substituted polychlorinated biphenyls (IUPAC number)	**CAS number**
2,3,3',4,4'-Pentachlorobiphenyl (PCB 105)	32598-14-4
2,3',4,4',5-Pentachlorobiphenyl (PCB 118)	31508-00-6
2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156)	38380-08-4
2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	69782-90-7
2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	52663-72-6
2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	39635-31-9

with the polychlorinated dioxins and furans, these two special classes of PCBs are often referred to as "dioxin-like" chemicals because they act in the body through a similar mechanism. Structural nomenclature is available at: http://www.epa.gov/oswer/riskassessment/pdf/1340-erasc-003.pdf. Commonly measured polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, and coplanar and mono-*ortho*-substituted PCBs are listed in the table.

In the environment, these dioxin-like chemicals are persistent and usually occur as a mixture of congeners (i.e., compounds that differ by the numbers and positions of chlorine atoms attached to the dibenzo-*p*-dioxin, dibenzofuran, or biphenyl structures). The general population is exposed to low levels of polychlorinated dibenzo-*p*-dioxins and dibenzofurans primarily through ingestion of high-fat foods such as dairy products, eggs, and animal fats, and some fish and wildlife. Dioxin-like chemicals are measurable in U.S. meats and poultry (Hoffman et al., 2006) as a result of the accumulation of these substances in the food chain. Breast milk is a substantial source of exposure for infants (Beck et al., 1994; Lundqvist et al., 2006), though breast milk levels have been decreasing in recent years (Arisawa et al., 2005). The lesser chlorinated PCBs, including some dioxin-like PCBs, are more volatile. These PCBs can enter air of buildings containing joint sealants made with PCBs prior to 1980 and can increase background serum levels via inhalational exposure (Johansson et al., 2003; Kohler et al., 2005). Volatilization of PCBs from nearby hazardous waste sites may also contribute to human inhalational exposure. Exposure to high levels of these chemicals has occurred in the past as a result of industrial accidents (e.g., after an explosion in a factory in Seveso, Italy); the use of accidentally contaminated cooking oils (e.g., as occurred in Yusho in Japan and Yucheng in Taiwan); the spraying of herbicides contaminated with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) (e.g., as Agent Orange in Vietnam); and the burning of PCBs producing polychlorinated dibenzofurans

Serum 1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin (HpCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**58.2** (<LOD-63.6)	**86.0** (75.5-96.7)	**112** (101-131)	1894
	01-02	**39.0** (33.7-45.0)	**40.2** (34.9-46.9)	**68.7** (56.7-82.2)	**115** (88.2-138)	**147** (126-181)	1220
	03-04	**25.3** (23.4-27.3)	**24.9** (22.8-26.9)	**42.5** (38.8-48.1)	**70.4** (62.7-80.1)	**91.3** (73.5-117)	1874
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	**63.6** (<LOD-75.6)	657
	01-02	†	†	†	†	†	†
	03-04	**16.7** (15.1-18.4)	**16.4** (15.1-18.3)	**23.6** (21.5-25.8)	**33.4** (28.6-36.8)	**46.7** (34.5-78.1)	586
20 years and older	99-00	*	< LOD	**62.0** (57.1-66.7)	**92.9** (81.2-101)	**120** (102-139)	1237
	01-02	**39.0** (33.7-45.0)	**40.2** (34.9-46.9)	**68.7** (56.7-82.2)	**115** (88.2-138)	**147** (126-181)	1220
	03-04	**26.8** (24.6-29.2)	**27.3** (24.6-29.0)	**45.6** (41.3-53.2)	**73.7** (64.1-88.6)	**95.0** (76.1-126)	1288
Gender							
Males	99-00	*	< LOD	< LOD	**73.6** (69.0-80.8)	**94.7** (83.1-103)	910
	01-02	**36.6** (31.7-42.3)	**39.0** (33.3-42.6)	**62.1** (49.7-75.0)	**102** (75.8-132)	**138** (103-169)	553
	03-04	**24.2** (21.7-27.0)	**23.2** (21.1-25.6)	**40.6** (35.3-46.9)	**64.2** (58.8-73.7)	**85.0** (65.8-113)	920
Females	99-00	*	< LOD	**62.7** (<LOD-69.1)	**102** (86.0-118)	**131** (111-164)	984
	01-02	**41.2** (34.9-48.7)	**43.6** (35.3-52.4)	**76.0** (59.5-90.1)	**125** (93.4-150)	**158** (130-191)	667
	03-04	**26.3** (24.4-28.3)	**26.8** (24.3-28.3)	**44.4** (41.1-50.2)	**76.1** (65.3-89.1)	**95.7** (80.7-128)	954
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**61.4** (<LOD-69.0)	**97.7** (82.8-111)	**132** (108-159)	621
	01-02	**39.6** (35.7-43.9)	**39.7** (33.6-47.4)	**64.0** (55.8-74.7)	**107** (82.4-128)	**149** (111-171)	262
	03-04	**25.8** (22.6-29.4)	**26.1** (20.9-30.9)	**41.9** (36.7-44.7)	**61.0** (49.7-71.9)	**80.1** (65.0-89.1)	424
Non-Hispanic blacks	99-00	*	< LOD	**58.1** (<LOD-71.1)	**95.0** (75.1-110)	**125** (102-183)	408
	01-02	**43.7** (35.4-54.0)	**42.8** (32.2-59.8)	**80.6** (60.9-106)	**134** (101-166)	**167** (130-230)	218
	03-04	**25.8** (22.6-29.4)	**23.7** (20.7-27.1)	**41.2** (32.6-56.4)	**69.2** (54.6-115)	**115** (67.1-164)	454
Non-Hispanic whites	99-00	*	< LOD	**59.0** (<LOD-64.8)	**84.9** (72.0-97.0)	**106** (96.7-122)	709
	01-02	**39.3** (33.0-46.8)	**40.5** (34.0-50.1)	**71.0** (56.3-87.5)	**117** (87.1-147)	**147** (125-186)	657
	03-04	**25.0** (22.6-27.7)	**24.6** (22.3-27.4)	**42.6** (39.4-48.5)	**73.5** (60.4-86.7)	**93.7** (71.6-127)	875

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 55.9, 10.3, and 13.0, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

(e.g., such as from electrical transformer fires). Workplace exposures are infrequent today, but incineration plant workers and chemical synthesis workers can be exposed via inhalation and dust exposures. The dioxin-like chemicals are easily absorbed, tend to distribute into body fat, have limited metabolism, and slow elimination from the body. Serum levels may be influenced by both past (stored in body fat) and recent exposures, though the current intakes for most people are now low. Half-lives of the dioxins and furans in the body vary from three to 19 years, with the half-life of TCDD estimated at around seven years (Geyer et al., 2002).

Because exposure to these chemicals includes a mixture of varying congeners, congener-specific effects are difficult to determine (Masuda, 2001; Masuda et al., 1998). However, these four groups of chemicals (polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, and the coplanar and mono-*ortho*- substituted PCBs) are considered to act through a similar mechanism to produce toxic effects. These dioxin-like effects are thought to result from interaction with the aryl hydrocarbon receptor (AhR), particularly in the induction of gene expression for cytochromes P450, CYP1A1 and CYP1A2. Dioxins and furans have a planar configuration and require four lateral chlorine atoms (2,3,7,8 positions) on the dibenzo-*p*-dioxin or dibenzofuran backbone to bind this receptor. The rank order of interaction with the AhR receptor by degree and position of chlorination is roughly similar for both the dioxin and furan series. The coplanar polychlorinated biphenyls (unsubstituted at *ortho* positions) and the mono-*ortho*-substituted polychlorinated biphenyls (which contain a chlorine atom at one of the *ortho* positions) can achieve a planar configuration and also interact with the AhR receptor. The variation in the effect on AhR among the dioxin-like chemicals is 10,000-fold, with TCDD and 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin being the most potent. To compare potency, each of these congeners has been assigned a potency value relative to

Serum 1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin (HpCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**354** (<LOD384)	**564** (501-617)	**749** (646-869)	1894
	01-02	**252** (219-289)	**267** (232-305)	**440** (376-529)	**779** (591-989)	**1030** (840-1290)	1220
	03-04	**155** (143-167)	**150** (134-163)	**288** (242-319)	**465** (399-550)	**618** (516-787)	1874
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	**289** (<LOD340)	657
	01-02	†	†	†	†	†	†
	03-04	**84.6** (77.4-92.5)	**83.9** (76.1-92.0)	**118** (106-131)	**165** (139-185)	**210** (176-319)	586
20 years and older	99-00	*	< LOD	**385** (354-418)	**610** (534-677)	**802** (681-936)	1237
	01-02	**252** (219-289)	**267** (232-305)	**440** (376-529)	**779** (591-989)	**1030** (840-1290)	1220
	03-04	**169** (155-184)	**170** (150-186)	**314** (267-348)	**506** (419-576)	**628** (546-810)	1288
Gender							
Males	99-00	*	< LOD	< LOD	**489** (436-543)	**613** (535-681)	910
	01-02	**243** (211-279)	**245** (213-291)	**422** (349-527)	**766** (536-976)	**983** (766-1260)	553
	03-04	**150** (135-167)	**144** (129-161)	**273** (236-305)	**424** (365-516)	**554** (440-667)	920
Females	99-00	*	< LOD	**373** (<LOD428)	**637** (562-802)	**907** (806-1040)	984
	01-02	**260** (221-306)	**281** (236-324)	**466** (386-551)	**795** (621-997)	**1140** (849-1330)	667
	03-04	**159** (147-172)	**158** (138-170)	**303** (249-345)	**520** (429-591)	**623** (545-848)	954
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**372** (<LOD404)	**598** (546-657)	**849** (657-1020)	621
	01-02	**254** (232-278)	**249** (229-286)	**403** (360-521)	**791** (643-929)	**988** (817-1240)	262
	03-04	**158** (139-180)	**159** (138-193)	**274** (241-299)	**414** (349-469)	**556** (451-592)	424
Non-Hispanic blacks	99-00	*	< LOD	**323** (<LOD391)	**567** (422-716)	**778** (574-1130)	408
	01-02	**258** (208-319)	**262** (180-339)	**478** (343-600)	**852** (578-1170)	**1170** (821-1660)	218
	03-04	**148** (128-170)	**137** (117-156)	**247** (188-344)	**434** (345-599)	**715** (405-1090)	454
Non-Hispanic whites	99-00	*	< LOD	**370** (<LOD401)	**565** (491-634)	**733** (637-816)	709
	01-02	**255** (216-302)	**277** (228-328)	**442** (374-547)	**782** (551-1020)	**1020** (803-1290)	657
	03-04	**155** (140-170)	**152** (131-171)	**292** (248-325)	**492** (390-571)	**621** (506-810)	875

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

TCDD (toxic equivalency factor [TEF]). When each TEF is multiplied by the concentration of the congener, a toxic equivalency (TEQ) value is obtained. Thus, the dioxin-like toxicity contributed by each of the polychlorinated dibenzo-*p*-dioxins, dibenzofurans, and PCBs can then be compared. The sum of all congener TEQs in a specimen (total TEQ) can be used to compare dioxin-like activity among specimens. Many of the dioxin-like PCBs have lower potency but are found at higher concentrations than TCDD (Kang et al., 1997; Patterson et al., 1994, Van den Berg et al., 2006), so these less potent chemicals may still contribute substantially to the total TEQ.

In animal studies, TCDD and dioxin-like chemicals have demonstrated many effects including: altered transcription of genes; induction of various enzymes; wasting syndrome; hepatotoxicity; altered immune function; testicular atrophy; altered thyroid function; chloracne; porphyria; neurotoxicity; teratogenicity; and carcinogenicity (EPA, 2004). Since animal species differ dramatically in sensitivity to these chemicals, it is difficult to predict human health effects though animal studies have provided support to observations of effects in human populations. Health effects of exposure to dioxin-like chemicals in people have been observed as a result of industrial or accidental exposures involving large doses of these chemicals. Chloracne, biochemical liver test abnormalities, elevated blood lipids, fetal injury, and porphyria cutanea tarda have been reported in episodes of high exposure. Developmental effects in humans are of concern since congenital anomalies and intrauterine growth retardation were observed in offspring of Yucheng mothers exposed to cooking oil contaminated with electrical oil containing very high levels of PCB and polychlorinated dibenzofurans. Environmental serum levels of primarily non-dioxin-like PCBs, and some dioxin-like chemicals, have been associated with altered psychomotor development in newborns and children (Arisawa et al., 2005; Jacobsen and Jacobsen, 1996; Koopman-Esseboom et al., 1996; Longnecker et al., 2003; Lundqvist et al., 2006; U.S. EPA, 2004; also see section on Non-Dioxin-Like Polychlorinated Biphenyls).

Cross-sectional associations of type II diabetes or markers of insulin resistance with serum levels of TCDD, other dioxin-like chemicals, non-dioxin-like PCBs and organochlorine pesticides have been reported in both highly exposed and environmentally exposed human populations, though some studies have not found an association (Calvert et al., 1999; Everett et al., 2007; Fierens et al., 2003; Fujiyoshi et al., 2006; Henriksen et al., 1997; Kang et al., 2006; Kern et al.,

Serum 1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	**10.7** (<LOD-13.9)	**14.9** (11.7-20.0)	1239
	03-04	*	< LOD	< LOD	< LOD	< LOD	1861
Age group							
12-19 years	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	582
20 years and older	01-02	*	< LOD	< LOD	**10.7** (<LOD-13.9)	**14.9** (11.7-20.0)	1239
	03-04	*	< LOD	< LOD	< LOD	< LOD	1279
Gender							
Males	01-02	*	< LOD	< LOD	**10.9** (<LOD-14.3)	**14.7** (11.5-17.6)	566
	03-04	*	< LOD	< LOD	< LOD	< LOD	914
Females	01-02	*	< LOD	< LOD	**10.7** (<LOD-14.1)	**15.6** (11.1-23.0)	673
	03-04	*	< LOD	< LOD	< LOD	< LOD	947
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	**9.20** (<LOD-11.8)	263
	03-04	*	< LOD	< LOD	< LOD	< LOD	421
Non-Hispanic blacks	01-02	*	< LOD	< LOD	**13.9** (<LOD-17.6)	**18.3** (13.9-23.0)	220
	03-04	*	< LOD	< LOD	< LOD	< LOD	450
Non-Hispanic whites	01-02	*	< LOD	< LOD	**11.3** (<LOD-14.4)	**15.1** (12.0-20.5)	672
	03-04	*	< LOD	< LOD	< LOD	< LOD	870

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 9.0 and 11.9.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

2004; Lee et al., 2006; Michalek et al., 1999, and 2003;) and *in vitro* and *in vivo* animal studies have provided possible mechanistic plausibility. Immune effects of dioxin-like chemicals and non-dioxin-like PCBs have been reported in animal studies (Carpenter, 2006; U.S.EPA, 2004), but few or consistent effects in humans have been observed (Baccarelli et al., 2002; Halperin et al., 1998; Jung et al., 1998; IARC, 1997).

Similar to some other organochlorine-type chemicals, the dioxin-like chemicals weakly mimic or interfere with the action of estrogen; for instance, dioxin-like chemicals may decrease the effect of estrogen through induction of its metabolism. This action contrasts with the non-dioxin-like PCBs and their metabolites, which may have direct estrogenic action (Carpenter, 2006; Wang et al., 2006; Yoshida et al., 2005). Dioxin and other organochlorine chemicals have been shown to interfere with male and female reproductive development in experimental and wild animals, particularly during gestational exposure (Gao et al., 1999; Grey and Ostby, 1995; Roman et al., 1998; Sonne et al., 2006; Theobald et al., 1997). In studies of women with environmental or accidental exposures, associations between dioxin-like chemical exposures and various reproductive endpoints (Eskenazi et al., 2003; Lawson et al., 2004; Schnorr et al., 2001; Warner et al., 2004 and 2007) and endometriosis (Eskenazi et al., 2002; Fierens et al., 2003; Heilier et al., 2005; Hoffman et al., 2007) have been either absent or of unknown significance, though animal studies have demonstrated reproductive effects at high doses (Arisawa et al., 2005; U.S. EPA, 2004). In men, lowered levels of testosterone have been associated with environmental and occupational exposures to dioxin-like chemicals (Dhooge et al., 2006; Egeland et al., 1994; Gupta et al., 2006; Henriksen et al., 1996; Johnson et al., 2001; Sweeney et al., 1998) and gonadal atrophy and lowered testosterone levels have been observed in animal studies.

TCDD is classified separately by the IARC and NTP as a known human carcinogen. The U.S. EPA (2004) and IARC (1997) concluded that the aggregate evidence supports an association between high-dose TCDD exposure (e.g., encountered in contaminated occupational settings or massive unintentional releases) and increases in the all-cancer category (Steenland et al., 2004). The Institute of Medicine (2005) concluded that human epidemiologic evidence is sufficient for a positive association of herbicides contaminated with TCDD and an increased risk for non-Hodgkin's lymphoma, Hodgkin's lymphoma, chronic lymphocytic leukemia, and soft tissue sarcoma. Other individual polychlorinated dibenzo-*p*-dioxins and dibenzofurans have not been studied sufficiently for IARC

Serum 1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**< LOD**	**74.7** (<LOD-90.7)	**105** (81.2-139)	1239
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1861
Age group							
12-19 years	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	582
20 years and older	01-02	*	**< LOD**	**< LOD**	**74.7** (<LOD-90.7)	**105** (81.2-139)	1239
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1279
Gender							
Males	01-02	*	**< LOD**	**< LOD**	**73.6** (<LOD-90.7)	**105** (77.9-134)	566
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	914
Females	01-02	*	**< LOD**	**< LOD**	**74.7** (<LOD-90.7)	**102** (78.0-152)	673
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	947
Race/ethnicity							
Mexican Americans	01-02	*	**< LOD**	**< LOD**	**< LOD**	**71.2** (<LOD-118)	263
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	421
Non-Hispanic blacks	01-02	*	**< LOD**	**< LOD**	**82.1** (<LOD-130)	**130** (75.7-184)	220
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	450
Non-Hispanic whites	01-02	*	**< LOD**	**< LOD**	**77.5** (<LOD-97.1)	**105** (78.8-143)	672
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	870

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

to classify their human potential for carcinogenicity, although EPA considers these other chemicals as likely human carcinogens (U.S.EPA, 2004). Both IARC and NTP consider polychlorinated biphenyls as likely and probable human carcinogens. Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html and from U.S. EPA at: http://www.epa.gov/ncea/pdfs/dioxin/nas-review/.

Biomonitoring Information

Serum levels of the dioxin-like chemicals reflect accumulated exposure due to their storage in body fat and slow elimination. Observed differences between people in the levels of these chemicals are due in part to differences in environmental exposure. For instance, eating fish from the Great Lakes region can contain higher levels of certain dioxin-like chemicals, particularly coplanar PCBs and therefore can result in mean lipid adjusted serum concentrations that are several times background values in the U.S. population (Anderson et al., 1998; Falk et al., 1999; Hanrahan et al., 1999; Turyk et al., 2006). Observed differences between people may also be due to longer periods of accumulation of these persistent chemicals. Several studies have shown that levels of the more highly chlorinated dioxins, furans, and PCBs in serum or fat will increase with the age of the population studied (Falk et al., 1999; Geyer et al., 2002; Kang et al., 1997; Luotamo et al., 1991; Patterson et al., 1986). Many of the dioxins, furans and PCBs measured in a representative New Zealand population pooled sampling showed an increasing trend with age (Bates et al., 2004). Also, in a U.S. representative sample from NHANES 1999-2000, participants aged 20 years and older had higher levels than participants aged 12-19 years when levels at the higher percentiles of the more

Serum 1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**32.6** (28.3-38.2)	**56.9** (47.4-67.3)	**74.0** (68.3-82.4)	1885
	01-02	**34.6** (29.6-40.6)	**39.2** (32.7-44.7)	**60.8** (50.3-74.2)	**95.2** (76.2-120)	**128** (99.4-153)	1234
	03-04	**17.2** (15.7-18.9)	**20.0** (17.8-22.9)	**36.5** (32.2-40.0)	**53.0** (48.1-59.6)	**68.5** (59.6-74.9)	1871
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	**26.7** (20.2-29.6)	648
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	**16.1** (14.3-18.1)	**19.4** (16.4-27.7)	584
20 years and older	99-00	*	< LOD	**36.2** (31.5-40.7)	**62.8** (53.6-69.1)	**75.6** (70.5-84.2)	1237
	01-02	**34.6** (29.6-40.6)	**39.2** (32.7-44.7)	**60.8** (50.3-74.2)	**95.2** (76.2-120)	**128** (99.4-153)	1234
	03-04	**19.7** (17.8-21.8)	**23.8** (20.7-26.4)	**39.3** (35.4-42.2)	**56.6** (49.7-63.8)	**70.8** (60.7-82.2)	1287
Gender							
Males	99-00	*	< LOD	**31.5** (23.7-38.2)	**55.0** (45.7-64.2)	**71.3** (59.4-79.4)	908
	01-02	**34.1** (28.3-41.1)	**38.9** (32.1-44.7)	**61.9** (50.0-79.5)	**94.9** (70.8-131)	**130** (88.5-181)	564
	03-04	**17.5** (15.5-19.8)	**19.8** (17.8-21.6)	**35.5** (29.8-40.3)	**52.9** (45.4-63.2)	**70.2** (57.5-88.7)	920
Females	99-00	*	< LOD	**34.9** (29.1-39.7)	**61.2** (51.0-69.2)	**74.9** (68.4-92.2)	977
	01-02	**35.1** (29.9-41.2)	**40.1** (32.4-46.3)	**59.8** (49.8-72.3)	**97.6** (77.1-114)	**126** (108-142)	670
	03-04	**16.9** (15.3-18.6)	**20.5** (17.8-24.6)	**36.9** (33.2-41.0)	**53.6** (48.3-59.6)	**65.6** (60.0-73.4)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**21.3** (<LOD-27.6)	**43.3** (34.1-52.3)	**58.0** (49.5-64.8)	624
	01-02	**18.3** (15.6-21.4)	**21.2** (19.4-25.0)	**31.9** (27.5-40.3)	**51.5** (40.3-69.9)	**68.3** (48.0-111)	260
	03-04	*	< LOD	**21.1** (16.3-26.5)	**32.2** (24.5-47.4)	**43.0** (31.5-65.3)	424
Non-Hispanic blacks	99-00	*	< LOD	**31.9** (26.6-41.2)	**56.7** (44.9-74.6)	**81.6** (72.2-91.7)	402
	01-02	**38.9** (33.6-45.0)	**40.3** (33.5-47.3)	**63.5** (54.6-76.9)	**93.9** (78.7-133)	**136** (92.6-185)	219
	03-04	**16.2** (12.9-20.4)	**18.1** (14.4-21.6)	**34.9** (28.4-42.9)	**54.5** (44.4-69.4)	**74.0** (54.3-122)	454
Non-Hispanic whites	99-00	*	< LOD	**35.5** (29.7-40.0)	**60.9** (51.4-68.3)	**74.3** (68.3-83.0)	703
	01-02	**37.8** (31.5-45.4)	**42.8** (33.9-51.2)	**65.0** (52.3-82.9)	**99.6** (78.4-130)	**131** (103-165)	671
	03-04	**18.7** (17.0-20.6)	**22.9** (19.9-26.2)	**38.0** (35.2-41.5)	**56.6** (48.7-63.8)	**69.0** (60.6-74.9)	872

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 20.1, 9.1, and 12.3, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

highly chlorinated congeners were compared (CDC, 2005). Similarly, the TEQ increased with age in an analysis of the NHANES 2003-2004 subsample (Patterson et al., 2009). Other factors also explain differences in levels observed between people. In a TEQ analysis of the NHANES 2001-2002 subsample, the total TEQ increased with age, was lower for Mexican Americans than non-Hispanic whites or blacks, and was higher in smokers than nonsmokers older than 60 years of age (Ferriby et al., 2007). Body mass is also a factor associated with increasing levels of some polychlorinated dibenzo-*p*-dioxins (Collins et al., 2007; Michalek et al., 1999). Gender is another predictor of levels of some dioxin-like chemicals. Compared with Japanese men, women had higher levels of octachlorodibenzo-*p*-dioxin, 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin, and 1,2,3,7,8,9-hexachlorodibenzo-*p*-dioxin, but men had higher levels of PCBs 169, 156, and 189 (Arisawa et al., 2003). In the NHANES 2001-2002 subsample, females had higher adjusted geometric mean levels than males for 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin, and 3,3’,4,4’,5-pentachlorobiphenyl (PCB 126). However, males had higher levels than females for 3,3’,4,4’,5,5’-hexachlorobiphenyl (PCB 169) (CDC, 2005).

The generally low lipid-adjusted levels observed in the U.S. representative NHANES subsamples of 1999-2000, 2001-2002, and 2003-2004 support the observation that human serum levels of polychlorinated dibenzo-*p*-dioxins, dibenzofurans, and PCBs have decreased by more than 80% since the 1980s (Aylward and Hays, 2002; Lorber, 2002; Patterson et al., 2009). Levels of some dioxin-like chemicals, such as the hexachlordibenzo-*p*-dioxins, were shown to decrease gradually from 1993 to 2003 in pooled samples from children in selected regions of Germany, whereas the hexachlordibenzofuran levels showed little change (Link et al., 2005). The levels of polychlorinated dibenzo-*p*-dioxins, dibenzofurans, and coplanar and mono-*ortho*-substituted biphenyls seen in the U.S. population

Serum 1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**202** (168-239)	**374** (314-426)	**496** (429-571)	1885
	01-02	**224** (192-261)	**247** (219-287)	**412** (347-498)	**663** (549-785)	**870** (696-1100)	1234
	03-04	**105** (95.7-116)	**123** (111-136)	**240** (219-263)	**357** (325-395)	**443** (395-487)	1871
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	**126** (93.2-155)	648
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	**77.6** (67.4-84.8)	**94.5** (77.6-122)	584
20 years and older	99-00	*	< LOD	**232** (196-268)	**403** (349-458)	**521** (458-607)	1237
	01-02	**224** (192-261)	**247** (219-287)	**412** (347-498)	**663** (549-785)	**870** (696-1100)	1234
	03-04	**124** (112-138)	**146** (125-172)	**259** (235-285)	**376** (334-422)	**466** (403-528)	1287
Gender							
Males	99-00	*	< LOD	**189** (134-239)	**353** (278-417)	**449** (378-526)	908
	01-02	**226** (190-270)	**263** (223-301)	**425** (347-540)	**678** (547-794)	**883** (666-1180)	564
	03-04	**108** (95.4-123)	**123** (108-141)	**231** (206-261)	**351** (286-424)	**450** (374-538)	920
Females	99-00	*	< LOD	**213** (174-263)	**400** (344-467)	**553** (467-651)	977
	01-02	**222** (190-260)	**239** (207-281)	**397** (338-474)	**644** (526-771)	**864** (720-1060)	670
	03-04	**103** (92.8-113)	**121** (101-142)	**249** (225-277)	**363** (336-395)	**429** (395-512)	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**128** (<LOD-167)	**284** (242-334)	**380** (328-419)	624
	01-02	**117** (99.4-139)	**130** (107-157)	**233** (198-270)	**409** (278-524)	**524** (384-731)	260
	03-04	*	< LOD	**141** (106-188)	**221** (188-337)	**327** (210-426)	424
Non-Hispanic blacks	99-00	*	< LOD	**191** (150-234)	**374** (267-424)	**477** (389-568)	402
	01-02	**229** (199-264)	**229** (190-284)	**371** (333-477)	**643** (480-799)	**821** (596-1260)	219
	03-04	**92.9** (73.3-118)	**106** (77.0-125)	**219** (165-260)	**362** (279-460)	**461** (372-689)	454
Non-Hispanic whites	99-00	*	< LOD	**222** (183-270)	**403** (346-460)	**520** (450-615)	703
	01-02	**246** (206-293)	**275** (233-325)	**443** (365-553)	**684** (549-870)	**897** (718-1150)	671
	03-04	**116** (105-127)	**136** (120-165)	**258** (231-286)	**375** (333-418)	**466** (402-519)	872

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

are generally well below the levels associated with occupational or unintentional exposures that have produced health effects. There are no firmly established relationships between concentrations (mainly considering TCDD) and health effects in people. Observations following industrial and accidental exposures have suggested that acute exposures resulting in serum concentrations of about 800 pg/g of lipid might be necessary to induce clinical effects such as chloracne, although levels in the thousands of pg/g of lipid do not always produce this effect (Mocarelli et al., 1991). Such studies of clinical effects in people after large unintentional exposures have measured concentrations ranging from several hundred to the tens of thousands of pg/g of lipid of TCDD or equivalent (Eskenazi et al., 2004; Masuda, 2001; Masuda et al., 1998; Mocarelli et al., 1991). However, it has been suggested that background total TEQ for the general population are about 10-100 times the TEQ levels associated with a possible risk for adaptive or subclinical adverse effects (e.g., endocrine changes) (U.S.EPA, 2004).

In general, observations of the levels of dioxin-like chemicals across percentiles in the NHANES 2003-2004 subsample appear roughly similar to previous NHANES surveys. Note that for some chemicals, detection rates and percentile values will change over survey periods due to improvements in analytical methods and limitations of sample volume. In keeping with results from reports from Germany (Papke et al., 1998), New Zealand (Bates et al., 2004) and elsewhere, U.S. NHANES subsamples have shown that the highly chlorinated and laterally substituted congeners are detected most often (CDC, 2005, Patterson et al., 2009). The following listed dioxin-like chemicals were detectable in greater than 10% of the NHANES 2003-2004 subsample (those in bold letters were detectable in greater than 60% of the subsample). Many of these contribute to a

Serum 1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin (HxCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1870
	01-02	*	< LOD	< LOD	**12.5** (10.5-15.3)	**17.0** (14.3-20.0)	1238
	03-04	*	< LOD	< LOD	< LOD	< LOD	1869
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	642
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	585
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1228
	01-02	*	< LOD	< LOD	**12.5** (10.5-15.3)	**17.0** (14.3-20.0)	1238
	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	895
	01-02	*	< LOD	< LOD	**12.1** (<LOD-14.8)	**15.1** (12.9-18.5)	567
	03-04	*	< LOD	< LOD	< LOD	< LOD	918
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	975
	01-02	*	< LOD	< LOD	**13.0** (10.7-16.8)	**18.3** (15.7-21.1)	671
	03-04	*	< LOD	< LOD	< LOD	< LOD	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	618
	01-02	*	< LOD	< LOD	**9.60** (<LOD-11.6)	**12.2** (<LOD-20.6)	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	396
	01-02	*	< LOD	< LOD	**14.6** (11.2-20.0)	**19.9** (14.6-23.9)	220
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	701
	01-02	*	< LOD	< LOD	**12.9** (9.90-15.9)	**17.3** (14.7-20.6)	672
	03-04	*	< LOD	< LOD	< LOD	< LOD	871

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 20.3, 9.3, and 12.3, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

significant portion of the total TEQ. The total TEQ at the 90th percentile of the U.S. population in NHANES 2003-2004 was 30.0 pg/g of lipid (Patterson et al. 2009).

- **1,2,3,4,6,7,8,9-octachlorodibenzo-*p*-dioxin**
- **1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin**
- **1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin**
- 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin
- 2,3,7,8-tetachlordibenzo-*p*-dioxin
- **1,2,3,4,6,7,8-heptachlorodibenzofuran**
- 1,2,3,4,7,8-hexachlorodibenzofuran
- 2,3,4,7,8-pentachlorodibenzofuran
- coplanar PCBs **126** and 169
- mono-*ortho* substituted PCBs **105, 118, 156, 157, 167,** 189

Octachlorodibenzo-*p*-dioxin

Of the dioxins and furans measured in the U.S. representative subsamples of NHANES 1999-2000, 2001-2002, and 2003-2004, octachlorodibenzo-*p*-dioxin typically is present in the highest concentration, but contributes little to the TEQ, with the other commonly detected dioxin and furan congeners being more than eight-fold lower in concentration. Levels of octachlorodibenzo-*p*-dioxin that were similar to slightly higher than those in these NHANES subsamples were seen in a representative pooled sampling New Zealander residents aged 15 years and older obtained during 1997-1998 and also in a small convenience sample of German residents aged 18-71 years in 1996 (Bates et al., 2004; Papke et al., 1998; CDC, 2005). Similar levels were also found in 232 Belgian blood donors in 2000 (Debacker et al., 2007).

Hexachlorodibenzo-*p*-dioxins

The three major hexachlorodibenzo-*p*-dioxins are assigned equal TEF values, but the 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin often demonstrates multifold higher concentrations than the other two hexachlorodibenzo-

Serum 1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin (HxCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1870
	01-02	*	< LOD	< LOD	**86.5** (68.8-108)	**121** (99.5-146)	1238
	03-04	*	< LOD	< LOD	< LOD	< LOD	1869
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	642
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	585
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1228
	01-02	*	< LOD	< LOD	**86.5** (68.8-108)	**121** (99.5-146)	1238
	03-04	*	< LOD	< LOD	< LOD	< LOD	1284
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	895
	01-02	*	< LOD	< LOD	**84.1** (<LOD-104)	**108** (90.6-142)	567
	03-04	*	< LOD	< LOD	< LOD	< LOD	918
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	975
	01-02	*	< LOD	< LOD	**89.8** (67.9-121)	**123** (102-157)	671
	03-04	*	< LOD	< LOD	< LOD	< LOD	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	618
	01-02	*	< LOD	< LOD	**74.7** (<LOD-104)	**107** (<LOD-167)	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	396
	01-02	*	< LOD	< LOD	**92.6** (62.8-126)	**123** (82.6-169)	220
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	701
	01-02	*	< LOD	< LOD	**88.1** (67.9-119)	**124** (96.6-152)	672
	03-04	*	< LOD	< LOD	< LOD	< LOD	871

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

p-dioxins; about six-fold higher in the NHANES 2001-2002 subsample (CDC, 2005). The unadjusted geometric mean levels of 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin in 2003-2004 and in 2001-2002 were 34.6 vs. 17.2 pg/g of lipid, respectively. The geometric mean levels of 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin in the 2001-2002 subsample were slightly higher than levels in either the German or New Zealand study mentioned above (Bates et al., 2004; Papke et al., 1998). A convenience sample of Japanese men and women aged 20-76 years studied during 1996-1997 also showed lower median levels than levels in the NHANES 2001-2002 subsample (Arisawa et al., 2003; CDC, 2005)

1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin

In prior NHANES surveys, 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin concentrations were nearly 60-fold lower than octachlorodibenzo-*p*-dioxin levels (at the comparable percentiles) (CDC, 2005), but because of a 10,000-fold greater TEF (equal to that of TCDD), the contribution of 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin to the total TEQ would be about 160 times greater than the octachlorodibenzo-*p*-dioxin. Levels of 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin for the total population at the 95th percentile in the NHANES 2001-2002 and 2003-2004 subsamples were 15.8 pg/g and 11.0 pg/g lipid, respectively. In 1996, a convenience sample of German residents aged 18-71 years showed that levels of 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin at the 95th percentile were 9.9 pg/g lipid (Papke et al., 1998). The 95th percentile of a group of workers with distant past trichlorophenol exposure was about twice as high as the 95th percentile for adults in NHANES 2001-2002 (CDC, 2005; Collins et al., 2006)

2,3,7,8-Tetrachlorodibenzo-*p*-dioxin

TCDD is considered the most potent of the dioxin-like

Serum 1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**406** (359-453)	**674** (597-767)	**913** (787-1010)	1921
	01-02	**346** (<LOD-394)	**333** (<LOD-402)	**573** (498-668)	**944** (780-1090)	**1260** (998-1610)	1171
	03-04	*	< LOD	**336** (283-389)	**582** (490-658)	**767** (645-913)	1851
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	**421** (363-517)	667
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	**244** (<LOD-330)	**352** (264-458)	581
20 years and older	99-00	*	< LOD	**445** (389-496)	**710** (624-802)	**948** (822-1080)	1254
	01-02	**346** (<LOD-394)	**333** (<LOD-402)	**573** (498-668)	**944** (780-1090)	**1260** (998-1610)	1171
	03-04	**220** (<LOD-244)	**223** (<LOD-243)	**358** (297-421)	**597** (502-719)	**794** (665-978)	1270
Gender							
Males	99-00	*	< LOD	< LOD	**517** (447-580)	**704** (563-838)	919
	01-02	*	< LOD	**442** (346-579)	**767** (593-968)	**1030** (837-1240)	517
	03-04	*	< LOD	**270** (244-320)	**457** (377-559)	**668** (501-856)	910
Females	99-00	*	< LOD	**504** (422-579)	**802** (674-928)	**1010** (928-1180)	1002
	01-02	**410** (356-472)	**405** (335-502)	**647** (574-751)	**1020** (858-1360)	**1450** (1060-1780)	654
	03-04	**235** (<LOD-256)	**238** (225-248)	**402** (321-486)	**640** (551-749)	**829** (675-1020)	941
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**418** (365-502)	**703** (610-873)	**940** (737-1230)	632
	01-02	*	< LOD	**432** (394-545)	**755** (578-1220)	**1150** (696-1640)	250
	03-04	*	< LOD	**296** (225-356)	**452** (363-540)	**588** (417-861)	419
Non-Hispanic blacks	99-00	*	< LOD	**444** (371-519)	**741** (566-983)	**1120** (799-1560)	411
	01-02	**421** (352-503)	**420** (339-509)	**682** (537-907)	**1110** (956-1520)	**1640** (1130-1900)	210
	03-04	*	< LOD	**345** (276-455)	**642** (513-883)	**926** (636-1310)	448
Non-Hispanic whites	99-00	*	< LOD	**391** (333-452)	**625** (562-754)	**861** (676-1010)	721
	01-02	**349** (<LOD-409)	**335** (<LOD-421)	**574** (496-679)	**945** (764-1170)	**1290** (972-1660)	632
	03-04	*	< LOD	**343** (282-403)	**585** (464-674)	**758** (635-922)	865

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 329.0, 319.0, and 218.0, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

chemicals and environmental exposure usually results in very low serum concentrations. In the NHANES 2003-2004 subsample, the 95th percentile for the total population (12 years and older) was 5.2 picograms/gram (pg/g) of lipid. In 1996, the 95th percentile for lipid adjusted serum TCDD levels in 139 Germans aged 18-71 years was 4.3 pg/g of lipid, with that percentile comprising mainly older individuals (Papke, 1998). In contrast, the most highly exposed females following the Seveso, Italy, factory explosion in 1976 had median lipid adjusted levels of 272 pg/g lipid (Eskenazi et al., 2004). TCDD levels in chemical plant workers with higher exposures have ranged as high as 2,000 pg/g lipid (IARC, 1997). Median serum TCDD levels measured in chemical production workers 15 years after workplace exposure ended were 68 pg/g of lipid (Calvert et al., 1996; Calvert et al., 1999). TCDD levels in the U.S. general population were also lower than workers with past trichlorophenol exposure (Collins et al., 2006) and lower than Vietnam veterans 20 years after duty-related exposure to Agent Orange (median serum TCDD concentration was 12.2 pg/g of lipid) (Henriksen et al., 1997).

Polychlorinated dibenzofurans

Of the polychlorinated dibenzofurans, the following could be characterized at the 95th percentiles (or lower) in the NHANES 1999-2000, 2001-2002 and 2003-2004 subsamples: 1,2,3,4,6,7,8-heptachlorodibenzofuran, 1,2,3,4,7,8-hexachlorodibenzofuran, 1,2,3,6,7,8-hexachlorodibenzofuran, and 2,3,4,7,8-pentachlorodibenzofuran. Generally, these levels are similar to other large population studies. In 237 workers with past exposure to trichlorophenol, where little polychlorinated dibenzofuran exposure would be expected, higher percentiles values were similar to a referent population and to the NHANES 1999-2000 and 2001-2002 subsamples (Collins et al., 2007; CDC, 2005). In 232 Belgian blood donors from the year 2000, the geometric mean level of 1,2,3,4,6,7,8-heptachlorodibenzofuran was several times lower than the geometric mean

Serum 1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**2530** (2230-2880)	**4260** (3770-4760)	**5950** (5090-6790)	1921
	01-02	**2230** (<LOD-2540)	**2170** (<LOD-2550)	**3860** (3180-4520)	**6460** (5140-8290)	**9110** (6940-11400)	1171
	03-04	*	**< LOD**	**2180** (1830-2540)	**3760** (3100-4540)	**5020** (4190-6070)	1851
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**1910** (1600-2340)	667
	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**1160** (<LOD1590)	**1780** (1160-2850)	581
20 years and older	99-00	*	**< LOD**	**2810** (2480-3110)	**4570** (4100-5020)	**6200** (5340-7300)	1254
	01-02	**2230** (<LOD-2540)	**2170** (<LOD-2550)	**3860** (3180-4520)	**6460** (5140-8290)	**9110** (6940-11400)	1171
	03-04	**1380** (<LOD-1540)	**1360** (<LOD-1470)	**2350** (1970-2900)	**4030** (3370-4700)	**5340** (4490-6370)	1270
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**3160** (2760-3760)	**4160** (3320-5570)	919
	01-02	*	**< LOD**	**3160** (2410-4070)	**5270** (4070-7140)	**7620** (6020-9760)	517
	03-04	*	**< LOD**	**1780** (1540-2070)	**3090** (2410-4020)	**4190** (3410-5350)	910
Females	99-00	*	**< LOD**	**3110** (2680-3560)	**5090** (4610-5740)	**6760** (5870-8710)	1002
	01-02	**2590** (2250-2980)	**2620** (2160-3000)	**4340** (3880-4860)	**6990** (5870-9040)	**10000** (7070-12300)	654
	03-04	**1420** (<LOD-1560)	**1410** (1300-1510)	**2700** (2210-3030)	**4340** (3750-4830)	**5770** (4590-6740)	941
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**2470** (2240-2990)	**4350** (3660-5570)	**6560** (5340-7590)	632
	01-02	*	**< LOD**	**3410** (2760-3860)	**5810** (4250-7670)	**8050** (5760-11800)	250
	03-04	*	**< LOD**	**1880** (1560-2220)	**3240** (2450-3880)	**3910** (3240-4630)	419
Non-Hispanic blacks	99-00	*	**< LOD**	**2520** (2090-2950)	**4770** (4040-5740)	**7140** (4740-10700)	411
	01-02	**2480** (2050-3000)	**2460** (2060-2970)	**4170** (3160-5560)	**7250** (5470-9920)	**9920** (7990-12000)	210
	03-04	*	**< LOD**	**2150** (1780-2880)	**3860** (3080-5640)	**5720** (3750-7830)	448
Non-Hispanic whites	99-00	*	**< LOD**	**2560** (2160-2910)	**4120** (3580-4780)	**5800** (4740-6790)	721
	01-02	**2270** (<LOD-2660)	**2200** (<LOD-2770)	**3860** (3090-4720)	**6530** (4890-8860)	**9150** (6630-12300)	632
	03-04	*	**< LOD**	**2220** (1830-2700)	**3770** (3040-4680)	**5050** (4190-6350)	865

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

value in the NHANES 2001-2002 subsample of adults and the other dibenzofurans examined in the Belgian donors were lower than the limits of detection in NHANES 2000-2001 (CDC, 2005; Debacker et al., 2007). In Yucheng rice oil contamination victims when examined 15 years after their exposure, levels of the polychlorinated dibenzofurans were still hundreds of times higher than in levels for the U.S. population observed in the NHANES subsamples in this *Report* (Hsu et al., 2005).

Coplanar PCBs

The coplanar PCBs typically contribute less than about 15% to the total TEQ in the U.S. population (Ferriby et al., 2007). In the NHANES 2001-2002 subsample, the geometric mean levels of PCBs 126 and 169 for adults aged 20 years and older were similar or slightly lower than those reported from a representative pooled sample of New Zealanders in 1996-1997 (Bates et al., 2004; CDC, 2005) and from a smaller sample of non-occupationally exposed men and women aged 20-76 years in Japan in 1999 (Arisawa et al., 2003). Higher levels of these PCBs have been reported for persons consuming sport fish caught in the Great Lakes region (Turyk et al., 2006). In 311 residents of northern Italy, serum PCB 126 and 169 were not detectable, though other PCBs tended to be higher than in the recent NHANES subsamples (Apostoli et al., 2005; CDC, 2005).

Mono-*ortho*-substituted PCBs

Of the mono-*ortho*-substituted PCB congeners, the most frequently detected in general population studies are PCBs 118 and 156. Of these, PCB 118 levels were higher than levels of PCB 156 in the NHANES 1999-2000, 2001-2002, and 2003-2004 subsamples, although PCB 156 contributes more to the TEQ because its TEF is five-fold greater than the TEF of PCB 118. Although these PCBs are relatively less potent (i.e., lower TEFs), their contribution

Serum 1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin (PeCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1915
	01-02	*	< LOD	< LOD	**11.3** (9.30-13.6)	**15.8** (13.3-19.8)	1236
	03-04	*	< LOD	**6.10** (5.50-6.80)	**9.00** (8.30-9.70)	**11.0** (9.90-12.2)	1878
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	659
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	**4.80** (<LOD-5.90)	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1256
	01-02	*	< LOD	< LOD	**11.3** (9.30-13.6)	**15.8** (13.3-19.8)	1236
	03-04	*	< LOD	**6.60** (5.90-7.20)	**9.30** (8.60-10.1)	**11.3** (10.1-12.7)	1290
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	920
	01-02	*	< LOD	< LOD	**10.8** (9.10-13.3)	**14.5** (11.7-19.4)	564
	03-04	*	< LOD	**5.90** (5.30-6.40)	**8.90** (7.90-9.60)	**11.0** (9.60-12.7)	923
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	995
	01-02	*	< LOD	**6.10** (<LOD-7.80)	**11.8** (9.40-14.3)	**16.6** (13.7-20.8)	672
	03-04	*	< LOD	**6.50** (5.70-7.20)	**9.10** (8.30-10.1)	**11.0** (10.0-12.2)	955
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	632
	01-02	*	< LOD	< LOD	< LOD	**8.70** (<LOD-12.7)	262
	03-04	*	< LOD	< LOD	**6.50** (5.20-7.90)	**7.80** (6.70-9.20)	425
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	**7.70** (<LOD-9.30)	**13.9** (9.60-18.4)	**18.4** (14.2-24.0)	218
	03-04	*	< LOD	**6.40** (5.30-8.20)	**9.90** (8.50-13.4)	**14.4** (9.60-20.1)	455
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	717
	01-02	*	< LOD	< LOD	**11.7** (9.50-14.3)	**16.7** (13.6-20.2)	672
	03-04	*	< LOD	**6.50** (5.80-7.10)	**9.30** (8.60-10.0)	**11.1** (10.1-12.2)	877

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 14.2, 6.0, and 4.5, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

to the total TEQ in the U.S. population is about 25% (Ferriby et al., 2007) since they are present in much higher concentrations than are the coplanar PCBs, dioxins, and furans. In a convenience sample of the U.S. population in 1988 (Patterson et al., 1994), levels of PCB 118 were five-fold higher than in the NHANES 1999-2002 subsamples (CDC, 2005). Comparable levels of PCB 156 levels in NHANES 1999-2000 are slightly lower than those reported for a Canadian population study in 1994 (Longnecker et al., 2000). In a referent population of 311 residents in northern Italy during 2001-2003, the 95th percentile levels of PCB 156 and PCB 118 were two to threefold higher than for the NHANES 1999-2002 subsamples (Apostoli et al., 2005; CDC, 2005). Levels of PCB 156 and PCB 118 were slightly higher in a Swedish study of 150 men than in the NHANES 1999-2000 subsample, possibly due to higher fish intake in the Swedish population (Glynn et al., 2000; CDC, 2005). However, in fish-consuming Japanese men and women studied during 1996-1997, PCB 118 levels at the 75th percentile were similar to levels in the NHANES 2001-2002 subsample (Arisawa et al., 2003).

Finding a measurable amount of one or more of the polychlorinated dibenzo-*p*-dioxins, dibenzofurans, coplanar or mono-*ortho*-substituted biphenyls in serum does not mean that the level of one or more of these chemicals causes an adverse health effect. Biomonitoring studies of serum polychlorinated dibenzo-*p*-dioxins, dibenzofurans, coplanar or mono-*ortho*-substituted biphenyls provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of polychlorinated dibenzo-*p*-dioxins, dibenzofurans, coplanar or mono-*ortho*-substituted biphenyls than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Serum 1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin (PeCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1915
	01-02	*	< LOD	< LOD	**77.8** (62.8-96.3)	**117** (90.3-133)	1236
	03-04	*	< LOD	**40.7** (37.4-43.0)	**60.3** (53.2-67.4)	**76.1** (66.9-87.4)	1878
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	659
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	**23.8** (<LOD-27.2)	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1256
	01-02	*	< LOD	< LOD	**77.8** (62.8-96.3)	**117** (90.3-133)	1236
	03-04	*	< LOD	**43.0** (39.2-47.8)	**63.5** (55.6-71.5)	**80.7** (67.9-89.9)	1290
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	920
	01-02	*	< LOD	< LOD	**76.1** (54.7-93.7)	**107** (83.5-133)	564
	03-04	*	< LOD	**39.3** (35.1-43.4)	**57.3** (49.3-66.1)	**67.8** (58.7-90.4)	923
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	995
	01-02	*	< LOD	**37.8** (<LOD-50.2)	**80.4** (62.9-107)	**121** (85.7-167)	672
	03-04	*	< LOD	**41.8** (37.7-45.2)	**63.6** (55.9-72.9)	**80.7** (70.5-88.3)	955
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	632
	01-02	*	< LOD	< LOD	< LOD	**66.0** (<LOD-111)	262
	03-04	*	< LOD	< LOD	**44.5** (34.2-52.0)	**52.8** (44.5-76.6)	425
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	**43.8** (<LOD-53.8)	**81.9** (58.2-117)	**123** (81.9-169)	218
	03-04	*	< LOD	**39.7** (30.6-48.0)	**67.3** (48.0-93.0)	**93.0** (66.7-137)	455
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	717
	01-02	*	< LOD	< LOD	**80.8** (61.6-107)	**121** (88.6-142)	672
	03-04	*	< LOD	**42.6** (38.6-45.1)	**63.4** (55.4-67.9)	**78.8** (67.9-84.7)	877

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1898
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1228
	03-04	*	**< LOD**	**< LOD**	**4.10** (<LOD-4.40)	**5.20** (4.30-5.80)	1876
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	658
	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	588
20 years and older	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1240
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1228
	03-04	*	**< LOD**	**< LOD**	**4.30** (3.90-4.60)	**5.30** (4.50-6.10)	1288
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	912
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	559
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**4.60** (3.80-5.30)	921
Females	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	986
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**6.40** (<LOD-9.20)	669
	03-04	*	**< LOD**	**< LOD**	**4.40** (4.00-4.90)	**5.50** (4.50-6.60)	955
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	630
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	262
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**3.80** (<LOD-5.50)	424
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	404
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**7.50** (<LOD-10.0)	217
	03-04	*	**< LOD**	**< LOD**	**4.50** (<LOD-6.10)	**6.20** (4.40-10.3)	454
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	709
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	665
	03-04	*	**< LOD**	**< LOD**	**4.10** (<LOD-4.50)	**5.20** (4.30-5.90)	877

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.1, 5.8, and 3.8, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1898
	01-02	*	< LOD	< LOD	< LOD	< LOD	1228
	03-04	*	< LOD	< LOD	**27.5** (<LOD-30.1)	**34.1** (30.2-39.6)	1876
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	658
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	588
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1240
	01-02	*	< LOD	< LOD	< LOD	< LOD	1228
	03-04	*	< LOD	< LOD	**28.6** (26.4-31.2)	**36.4** (31.5-42.7)	1288
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	912
	01-02	*	< LOD	< LOD	< LOD	< LOD	559
	03-04	*	< LOD	< LOD	< LOD	**28.8** (25.4-34.5)	921
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	986
	01-02	*	< LOD	< LOD	< LOD	**50.7** (<LOD-74.3)	669
	03-04	*	< LOD	< LOD	**30.2** (27.4-33.1)	**38.7** (32.3-44.5)	955
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	630
	01-02	*	< LOD	< LOD	< LOD	< LOD	262
	03-04	*	< LOD	< LOD	< LOD	**23.6** (<LOD-32.5)	424
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	404
	01-02	*	< LOD	< LOD	< LOD	**55.6** (<LOD-72.0)	217
	03-04	*	< LOD	< LOD	**31.1** (<LOD-42.0)	**42.4** (29.5-67.8)	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	709
	01-02	*	< LOD	< LOD	< LOD	< LOD	665
	03-04	*	< LOD	< LOD	**28.0** (<LOD-30.0)	**33.6** (31.1-38.8)	877

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**14.7** (<LOD-18.0)	**19.5** (17.4-23.0)	1709
	01-02	**9.64** (8.53-10.9)	**10.3** (8.80-11.7)	**14.6** (12.7-16.7)	**21.3** (18.0-25.5)	**27.1** (22.5-32.0)	1219
	03-04	*	< LOD	**10.6** (9.90-11.4)	**14.6** (13.1-16.5)	**18.7** (16.5-24.2)	1858
Age group							
12-19 years	99-00	*	< LOD	< LOD	**18.4** (16.2-20.9)	**24.7** (20.9-28.1)	600
	01-02	†	†	†	†	†	†
	03-04	**9.36** (8.60-10.2)	**8.80** (<LOD-9.80)	**13.4** (12.3-14.6)	**19.3** (16.2-29.6)	**33.2** (21.2-54.2)	583
20 years and older	99-00	*	< LOD	< LOD	**14.2** (<LOD-17.5)	**18.4** (15.0-23.8)	1109
	01-02	**9.64** (8.53-10.9)	**10.3** (8.80-11.7)	**14.6** (12.7-16.7)	**21.3** (18.0-25.5)	**27.1** (22.5-32.0)	1219
	03-04	*	< LOD	**10.3** (9.60-11.1)	**13.8** (12.5-16.0)	**18.0** (16.0-20.9)	1275
Gender							
Males	99-00	*	< LOD	< LOD	**16.4** (<LOD-20.0)	**21.0** (18.1-26.8)	815
	01-02	**10.1** (8.74-11.6)	**11.0** (9.30-12.6)	**15.2** (12.9-17.2)	**20.8** (17.2-27.8)	**28.9** (22.0-34.8)	557
	03-04	*	< LOD	**11.3** (10.1-12.9)	**17.1** (14.3-19.1)	**23.9** (18.3-30.9)	913
Females	99-00	*	< LOD	< LOD	< LOD	**17.5** (14.3-20.3)	894
	01-02	**9.28** (8.20-10.5)	**9.40** (8.20-11.2)	**14.1** (12.4-16.6)	**21.3** (17.4-25.5)	**26.5** (22.3-31.9)	662
	03-04	*	< LOD	**9.90** (9.30-10.5)	**13.0** (12.2-14.3)	**16.0** (14.3-18.4)	945
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**19.7** (<LOD-25.4)	570
	01-02	**7.73** (7.19-8.31)	**8.20** (7.80-8.70)	**11.2** (10.6-12.5)	**16.5** (14.5-19.6)	**20.8** (17.2-26.8)	260
	03-04	*	< LOD	**9.10** (<LOD-10.6)	**12.0** (10.1-16.8)	**15.1** (11.6-20.0)	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**22.4** (15.2-28.2)	**28.2** (26.5-29.6)	359
	01-02	**12.3** (10.6-14.4)	**12.8** (10.9-15.2)	**17.4** (15.4-21.0)	**25.5** (22.4-31.2)	**32.1** (25.7-37.6)	214
	03-04	*	< LOD	**11.3** (10.7-12.2)	**16.1** (13.4-19.0)	**20.4** (16.7-26.8)	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	**17.5** (14.9-18.9)	636
	01-02	**9.50** (8.30-10.9)	**10.1** (8.40-12.0)	**14.4** (12.6-16.6)	**20.5** (16.9-25.5)	**25.8** (20.5-31.7)	665
	03-04	*	< LOD	**10.5** (9.60-11.5)	**14.6** (12.9-17.4)	**19.0** (16.3-26.2)	864

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 13.5, 7.0, and 8.6, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**85.3** (<LOD-95.8)	**108** (95.8-120)	1709
	01-02	**62.2** (55.4-69.9)	**64.5** (58.0-71.6)	**94.1** (82.3-110)	**134** (119-165)	**181** (147-206)	1219
	03-04	*	< LOD	**63.6** (59.9-67.7)	**88.3** (81.0-100)	**116** (101-137)	1858
Age group							
12-19 years	99-00	*	< LOD	< LOD	**79.3** (69.5-84.2)	**102** (83.4-120)	600
	01-02	†	†	†	†	†	†
	03-04	**47.5** (44.0-51.3)	**43.7** (<LOD-49.3)	**63.7** (59.1-72.3)	**102** (85.3-114)	**175** (113-222)	583
20 years and older	99-00	*	< LOD	< LOD	**85.7** (<LOD-97.7)	**108** (93.6-127)	1109
	01-02	**62.2** (55.4-69.9)	**64.5** (58.0-71.6)	**94.1** (82.3-110)	**134** (119-165)	**181** (147-206)	1219
	03-04	*	< LOD	**63.5** (59.6-67.6)	**86.5** (78.8-100)	**112** (94.9-135)	1275
Gender							
Males	99-00	*	< LOD	< LOD	**91.4** (<LOD-108)	**112** (99.3-133)	815
	01-02	**66.3** (58.2-75.6)	**70.4** (59.8-81.8)	**99.3** (85.5-120)	**143** (120-181)	**182** (146-237)	557
	03-04	*	< LOD	**69.7** (62.9-76.0)	**100** (85.9-116)	**135** (113-193)	913
Females	99-00	*	< LOD	< LOD	< LOD	**97.8** (86.2-130)	894
	01-02	**58.8** (52.0-66.4)	**60.2** (53.5-67.6)	**89.5** (74.7-107)	**131** (108-165)	**169** (131-225)	662
	03-04	*	< LOD	**58.5** (54.5-62.4)	**83.5** (74.7-87.7)	**102** (87.7-116)	945
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**113** (<LOD-133)	570
	01-02	**49.5** (46.0-53.4)	**50.4** (45.7-57.2)	**76.9** (67.1-82.1)	**99.7** (90.9-124)	**133** (94.8-202)	260
	03-04	*	< LOD	**56.0** (<LOD-64.6)	**74.2** (62.6-91.4)	**90.5** (76.4-107)	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**117** (89.0-143)	**153** (109-197)	359
	01-02	**72.6** (61.9-85.2)	**70.9** (62.4-85.2)	**107** (91.5-128)	**147** (131-177)	**193** (154-259)	214
	03-04	*	< LOD	**66.2** (60.2-75.5)	**91.3** (80.3-112)	**119** (102-151)	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	**97.7** (89.3-104)	636
	01-02	**61.8** (54.3-70.4)	**65.4** (57.4-72.2)	**94.3** (78.1-112)	**133** (114-166)	**180** (137-222)	665
	03-04	*	< LOD	**63.9** (59.6-69.2)	**87.8** (79.8-100)	**116** (102-139)	864

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,7,8,9-Heptachlorodibenzofuran (HpCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	1224
	03-04	*	< LOD	< LOD	< LOD	< LOD	1852
Age group							
12-19 years	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	583
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1224
	03-04	*	< LOD	< LOD	< LOD	< LOD	1269
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	558
	03-04	*	< LOD	< LOD	< LOD	< LOD	908
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	666
	03-04	*	< LOD	< LOD	< LOD	< LOD	944
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	217
	03-04	*	< LOD	< LOD	< LOD	< LOD	452
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	661
	03-04	*	< LOD	< LOD	< LOD	< LOD	856

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 7.0 and 8.6.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,7,8,9-Heptachlorodibenzofuran (HpCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	1224
	03-04	*	< LOD	< LOD	< LOD	< LOD	1852
Age group							
12-19 years	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	583
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1224
	03-04	*	< LOD	< LOD	< LOD	< LOD	1269
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	558
	03-04	*	< LOD	< LOD	< LOD	< LOD	908
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	666
	03-04	*	< LOD	< LOD	< LOD	< LOD	944
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	217
	03-04	*	< LOD	< LOD	< LOD	< LOD	452
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	661
	03-04	*	< LOD	< LOD	< LOD	< LOD	856

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1890
	01-02	*	< LOD	**8.00** (6.90-9.60)	**12.1** (9.40-14.9)	**15.4** (12.9-18.6)	1223
	03-04	*	< LOD	< LOD	**7.50** (<LOD-7.90)	**8.90** (7.90-10.2)	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	657
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	583
20 years and older	99-00	*	< LOD	< LOD	< LOD	**12.8** (<LOD-14.5)	1233
	01-02	*	< LOD	**8.00** (6.90-9.60)	**12.1** (9.40-14.9)	**15.4** (12.9-18.6)	1223
	03-04	*	< LOD	< LOD	**7.60** (<LOD-8.20)	**9.50** (8.00-10.5)	1283
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	908
	01-02	*	< LOD	**8.20** (7.10-10.0)	**12.8** (9.50-15.9)	**15.9** (12.2-20.9)	562
	03-04	*	< LOD	< LOD	**7.40** (<LOD-8.00)	**8.50** (7.80-10.0)	916
Females	99-00	*	< LOD	< LOD	< LOD	**12.9** (<LOD-16.4)	982
	01-02	*	< LOD	**7.90** (6.70-9.00)	**11.7** (9.40-13.8)	**14.5** (12.2-18.6)	661
	03-04	*	< LOD	< LOD	**7.50** (<LOD-8.40)	**9.30** (7.80-10.4)	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	**7.30** (<LOD-8.00)	**8.00** (7.00-10.9)	261
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**14.3** (<LOD-15.1)	399
	01-02	*	< LOD	**8.90** (7.70-10.1)	**13.6** (11.1-17.1)	**18.6** (14.6-22.6)	214
	03-04	*	< LOD	< LOD	**7.80** (<LOD-10.9)	**10.9** (7.50-19.4)	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	703
	01-02	*	< LOD	**8.30** (7.10-10.2)	**12.5** (10.0-15.9)	**15.9** (13.1-19.0)	664
	03-04	*	< LOD	< LOD	**7.60** (<LOD-8.10)	**9.40** (8.00-10.2)	869

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.7, 6.5, and 7.4, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1890
	01-02	*	**< LOD**	**54.0** (46.5-63.6)	**82.3** (65.5-104)	**108** (88.0-138)	1223
	03-04	*	**< LOD**	**< LOD**	**49.1** (<LOD-54.5)	**60.1** (53.4-68.8)	1866
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	657
	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	583
20 years and older	99-00	*	**< LOD**	**< LOD**	**< LOD**	**84.2** (<LOD-97.2)	1233
	01-02	*	**< LOD**	**54.0** (46.5-63.6)	**82.3** (65.5-104)	**108** (88.0-138)	1223
	03-04	*	**< LOD**	**< LOD**	**51.0** (<LOD-57.2)	**62.2** (56.2-72.7)	1283
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	908
	01-02	*	**< LOD**	**56.9** (48.6-71.4)	**90.1** (71.1-108)	**108** (87.4-144)	562
	03-04	*	**< LOD**	**< LOD**	**49.3** (<LOD-54.9)	**59.3** (52.9-68.8)	916
Females	99-00	*	**< LOD**	**< LOD**	**< LOD**	**82.8** (<LOD-102)	982
	01-02	*	**< LOD**	**51.6** (43.7-59.6)	**76.1** (62.6-97.0)	**105** (81.6-140)	661
	03-04	*	**< LOD**	**< LOD**	**48.9** (<LOD-57.2)	**61.9** (53.3-72.7)	950
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	631
	01-02	*	**< LOD**	**< LOD**	**48.4** (<LOD-56.3)	**65.3** (48.6-79.4)	261
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	423
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**< LOD**	**90.8** (<LOD-105)	399
	01-02	*	**< LOD**	**52.7** (45.0-62.7)	**87.1** (63.7-108)	**122** (85.2-147)	214
	03-04	*	**< LOD**	**< LOD**	**56.9** (<LOD-71.7)	**71.7** (53.8-112)	453
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	703
	01-02	*	**< LOD**	**56.0** (48.6-66.1)	**84.2** (64.5-115)	**112** (88.6-142)	664
	03-04	*	**< LOD**	**< LOD**	**50.6** (<LOD-56.3)	**61.4** (54.0-71.8)	869

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,6,7,8-Hexachlorodibenzofuran (HxCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1898
	01-02	*	< LOD	**7.10** (<LOD-8.20)	**10.4** (9.00-13.1)	**14.0** (11.0-17.1)	1236
	03-04	*	< LOD	< LOD	< LOD	**8.80** (<LOD-9.80)	1868
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	656
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	585
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1242
	01-02	*	< LOD	**7.10** (<LOD-8.20)	**10.4** (9.00-13.1)	**14.0** (11.0-17.1)	1236
	03-04	*	< LOD	< LOD	< LOD	**9.00** (8.00-10.1)	1283
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	913
	01-02	*	< LOD	**7.10** (<LOD-8.60)	**11.3** (8.50-13.8)	**15.1** (11.3-18.7)	566
	03-04	*	< LOD	< LOD	< LOD	**9.10** (7.90-10.8)	918
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	985
	01-02	*	< LOD	**7.00** (6.20-8.00)	**10.0** (9.20-11.4)	**13.1** (10.5-15.6)	670
	03-04	*	< LOD	< LOD	< LOD	**8.50** (<LOD-9.20)	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	625
	01-02	*	< LOD	< LOD	< LOD	**6.90** (<LOD-11.1)	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	**7.60** (6.10-9.10)	**12.1** (10.0-14.1)	**16.0** (12.3-21.0)	219
	03-04	*	< LOD	< LOD	< LOD	**8.50** (<LOD-12.1)	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	708
	01-02	*	< LOD	**7.40** (6.20-9.00)	**10.7** (9.20-14.3)	**14.8** (11.6-17.2)	670
	03-04	*	< LOD	< LOD	< LOD	**9.10** (8.00-10.6)	871

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.6, 6.1, and 7.9, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,6,7,8-Hexachlorodibenzofuran (HxCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1898
	01-02	*	**< LOD**	**46.2** (<LOD-56.5)	**70.3** (58.4-90.7)	**101** (77.6-120)	1236
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**59.8** (<LOD-65.4)	1868
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	656
	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	585
20 years and older	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1242
	01-02	*	**< LOD**	**46.2** (<LOD-56.5)	**70.3** (58.4-90.7)	**101** (77.6-120)	1236
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**61.0** (57.6-65.7)	1283
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	913
	01-02	*	**< LOD**	**47.9** (<LOD-60.5)	**72.3** (57.5-105)	**104** (73.5-133)	566
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**61.0** (54.0-67.7)	918
Females	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	985
	01-02	*	**< LOD**	**45.0** (37.0-54.3)	**66.2** (58.3-79.1)	**90.7** (71.9-115)	670
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**58.1** (<LOD-65.0)	950
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	625
	01-02	*	**< LOD**	**< LOD**	**< LOD**	**52.7** (<LOD-65.9)	262
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	423
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	408
	01-02	*	**< LOD**	**44.4** (37.2-57.3)	**71.5** (59.8-90.9)	**107** (70.7-142)	219
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**58.4** (<LOD-73.0)	453
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	708
	01-02	*	**< LOD**	**49.6** (41.9-57.9)	**72.8** (58.4-102)	**103** (82.6-121)	670
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**63.4** (57.3-67.7)	871

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,7,8,9-Hexachlorodibenzofuran (HxCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1875
	01-02	*	< LOD	< LOD	< LOD	< LOD	1223
	03-04	*	< LOD	< LOD	< LOD	< LOD	1864
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	645
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	583
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1230
	01-02	*	< LOD	< LOD	< LOD	< LOD	1223
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	894
	01-02	*	< LOD	< LOD	< LOD	< LOD	559
	03-04	*	< LOD	< LOD	< LOD	< LOD	914
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	981
	01-02	*	< LOD	< LOD	< LOD	< LOD	664
	03-04	*	< LOD	< LOD	< LOD	< LOD	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	620
	01-02	*	< LOD	< LOD	< LOD	< LOD	261
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	400
	01-02	*	< LOD	< LOD	< LOD	< LOD	216
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	699
	01-02	*	< LOD	< LOD	< LOD	< LOD	665
	03-04	*	< LOD	< LOD	< LOD	< LOD	866

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.7, 6.0, and 8.3, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,7,8,9-Hexachlorodibenzofuran (HxCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1875
	01-02	*	< LOD	< LOD	< LOD	< LOD	1223
	03-04	*	< LOD	< LOD	< LOD	< LOD	1864
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	645
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	583
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1230
	01-02	*	< LOD	< LOD	< LOD	< LOD	1223
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	894
	01-02	*	< LOD	< LOD	< LOD	< LOD	559
	03-04	*	< LOD	< LOD	< LOD	< LOD	914
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	981
	01-02	*	< LOD	< LOD	< LOD	< LOD	664
	03-04	*	< LOD	< LOD	< LOD	< LOD	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	620
	01-02	*	< LOD	< LOD	< LOD	< LOD	261
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	400
	01-02	*	< LOD	< LOD	< LOD	< LOD	216
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	699
	01-02	*	< LOD	< LOD	< LOD	< LOD	665
	03-04	*	< LOD	< LOD	< LOD	< LOD	866

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,4,6,7,8-Hexachlorodibenzofuran (HxCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1884
	01-02	*	< LOD	< LOD	< LOD	< LOD	1230
	03-04	*	< LOD	< LOD	< LOD	< LOD	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	652
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	584
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1232
	01-02	*	< LOD	< LOD	< LOD	< LOD	1230
	03-04	*	< LOD	< LOD	< LOD	< LOD	1282
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	900
	01-02	*	< LOD	< LOD	< LOD	< LOD	565
	03-04	*	< LOD	< LOD	< LOD	< LOD	916
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	984
	01-02	*	< LOD	< LOD	< LOD	< LOD	665
	03-04	*	< LOD	< LOD	< LOD	< LOD	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	614
	01-02	*	< LOD	< LOD	< LOD	< LOD	260
	03-04	*	< LOD	< LOD	< LOD	< LOD	422
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	< LOD	< LOD	< LOD	218
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	704
	01-02	*	< LOD	< LOD	< LOD	< LOD	671
	03-04	*	< LOD	< LOD	< LOD	< LOD	869

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.9, 5.8, and 8.2, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,4,6,7,8-Hexachlorodibenzofuran (HxCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1884
	01-02	*	< LOD	< LOD	< LOD	< LOD	1230
	03-04	*	< LOD	< LOD	< LOD	< LOD	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	652
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	584
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1232
	01-02	*	< LOD	< LOD	< LOD	< LOD	1230
	03-04	*	< LOD	< LOD	< LOD	< LOD	1282
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	900
	01-02	*	< LOD	< LOD	< LOD	< LOD	565
	03-04	*	< LOD	< LOD	< LOD	< LOD	916
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	984
	01-02	*	< LOD	< LOD	< LOD	< LOD	665
	03-04	*	< LOD	< LOD	< LOD	< LOD	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	614
	01-02	*	< LOD	< LOD	< LOD	< LOD	260
	03-04	*	< LOD	< LOD	< LOD	< LOD	422
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	408
	01-02	*	< LOD	< LOD	< LOD	< LOD	218
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	704
	01-02	*	< LOD	< LOD	< LOD	< LOD	671
	03-04	*	< LOD	< LOD	< LOD	< LOD	869

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1884
	01-02	*	< LOD	< LOD	< LOD	< LOD	1202
	03-04	*	< LOD	< LOD	< LOD	< LOD	1849
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	652
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	581
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1232
	01-02	*	< LOD	< LOD	< LOD	< LOD	1202
	03-04	*	< LOD	< LOD	< LOD	< LOD	1268
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	904
	01-02	*	< LOD	< LOD	< LOD	< LOD	541
	03-04	*	< LOD	< LOD	< LOD	< LOD	905
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	980
	01-02	*	< LOD	< LOD	< LOD	< LOD	661
	03-04	*	< LOD	< LOD	< LOD	< LOD	944
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	623
	01-02	*	< LOD	< LOD	< LOD	< LOD	257
	03-04	*	< LOD	< LOD	< LOD	< LOD	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	404
	01-02	*	< LOD	< LOD	< LOD	< LOD	212
	03-04	*	< LOD	< LOD	< LOD	< LOD	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	705
	01-02	*	< LOD	< LOD	< LOD	< LOD	653
	03-04	*	< LOD	< LOD	< LOD	< LOD	857

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 35.6, 21.0, and 12.0, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1884
	01-02	*	< LOD	< LOD	< LOD	< LOD	1202
	03-04	*	< LOD	< LOD	< LOD	< LOD	1849
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	652
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	581
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1232
	01-02	*	< LOD	< LOD	< LOD	< LOD	1202
	03-04	*	< LOD	< LOD	< LOD	< LOD	1268
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	904
	01-02	*	< LOD	< LOD	< LOD	< LOD	541
	03-04	*	< LOD	< LOD	< LOD	< LOD	905
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	980
	01-02	*	< LOD	< LOD	< LOD	< LOD	661
	03-04	*	< LOD	< LOD	< LOD	< LOD	944
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	623
	01-02	*	< LOD	< LOD	< LOD	< LOD	257
	03-04	*	< LOD	< LOD	< LOD	< LOD	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	404
	01-02	*	< LOD	< LOD	< LOD	< LOD	212
	03-04	*	< LOD	< LOD	< LOD	< LOD	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	705
	01-02	*	< LOD	< LOD	< LOD	< LOD	653
	03-04	*	< LOD	< LOD	< LOD	< LOD	857

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,7,8-Pentachlorodibenzofuran (PeCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1922
	01-02	*	< LOD	< LOD	< LOD	< LOD	1235
	03-04	*	< LOD	< LOD	< LOD	< LOD	1867
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	663
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	586
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1259
	01-02	*	< LOD	< LOD	< LOD	< LOD	1235
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	920
	01-02	*	< LOD	< LOD	< LOD	< LOD	565
	03-04	*	< LOD	< LOD	< LOD	< LOD	917
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1002
	01-02	*	< LOD	< LOD	< LOD	< LOD	670
	03-04	*	< LOD	< LOD	< LOD	< LOD	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	637
	01-02	*	< LOD	< LOD	< LOD	< LOD	263
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	217
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	717
	01-02	*	< LOD	< LOD	< LOD	< LOD	670
	03-04	*	< LOD	< LOD	< LOD	< LOD	869

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 13.2, 5.8, and 7.1, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 1,2,3,7,8-Pentachlorodibenzofuran (PeCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1922
	01-02	*	< LOD	< LOD	< LOD	< LOD	1235
	03-04	*	< LOD	< LOD	< LOD	< LOD	1867
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	663
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	586
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1259
	01-02	*	< LOD	< LOD	< LOD	< LOD	1235
	03-04	*	< LOD	< LOD	< LOD	< LOD	1281
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	920
	01-02	*	< LOD	< LOD	< LOD	< LOD	565
	03-04	*	< LOD	< LOD	< LOD	< LOD	917
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1002
	01-02	*	< LOD	< LOD	< LOD	< LOD	670
	03-04	*	< LOD	< LOD	< LOD	< LOD	950
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	637
	01-02	*	< LOD	< LOD	< LOD	< LOD	263
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	217
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	717
	01-02	*	< LOD	< LOD	< LOD	< LOD	670
	03-04	*	< LOD	< LOD	< LOD	< LOD	869

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,4,7,8-Pentachlorodibenzofuran (PeCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**15.9** (13.7-17.1)	1895
	01-02	*	**< LOD**	**9.20** (7.50-11.1)	**14.3** (12.3-16.2)	**18.1** (16.1-21.1)	1230
	03-04	*	**< LOD**	**6.80** (<LOD-7.20)	**9.90** (8.90-10.7)	**12.3** (11.0-13.3)	1871
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	656
	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	586
20 years and older	99-00	*	**< LOD**	**< LOD**	**12.7** (<LOD-13.9)	**16.1** (14.1-17.6)	1239
	01-02	*	**< LOD**	**9.20** (7.50-11.1)	**14.3** (12.3-16.2)	**18.1** (16.1-21.1)	1230
	03-04	*	**< LOD**	**7.20** (<LOD-7.70)	**10.3** (9.40-11.2)	**13.0** (11.4-14.7)	1285
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**< LOD**	**13.9** (12.8-15.4)	906
	01-02	*	**< LOD**	**9.40** (7.30-11.6)	**14.1** (11.6-16.7)	**16.7** (14.0-22.8)	560
	03-04	*	**< LOD**	**7.00** (<LOD-7.30)	**9.80** (8.70-10.6)	**12.2** (10.4-14.8)	920
Females	99-00	*	**< LOD**	**< LOD**	**13.1** (<LOD-16.1)	**16.7** (14.3-19.2)	989
	01-02	*	**< LOD**	**9.10** (7.50-10.7)	**14.5** (13.0-16.1)	**18.5** (16.4-21.2)	670
	03-04	*	**< LOD**	**< LOD**	**10.3** (8.90-11.0)	**12.6** (11.0-13.7)	951
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	632
	01-02	*	**< LOD**	**< LOD**	**7.80** (6.10-9.80)	**9.80** (7.80-12.5)	264
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**7.90** (<LOD-10.5)	423
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**< LOD**	**16.3** (13.4-19.0)	400
	01-02	*	**< LOD**	**8.40** (6.80-9.30)	**14.1** (11.7-16.4)	**19.1** (15.1-23.0)	216
	03-04	*	**< LOD**	**< LOD**	**9.80** (8.00-13.9)	**15.9** (9.70-23.9)	454
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**15.6** (13.8-17.1)	706
	01-02	*	**5.90** (<LOD-6.90)	**10.3** (8.10-12.0)	**15.5** (13.0-17.6)	**18.5** (16.5-22.2)	665
	03-04	*	**< LOD**	**7.10** (<LOD-7.70)	**10.3** (9.10-11.2)	**12.4** (11.0-13.7)	873

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.7, 5.5, and 6.8, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,4,7,8-Pentachlorodibenzofuran (PeCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	**< LOD**	**< LOD**	**< LOD**	**103** (96.0-113)	1895
	01-02	*	**< LOD**	**60.8** (51.3-70.6)	**99.4** (83.4-114)	**134** (113-152)	1230
	03-04	*	**< LOD**	**44.2** (<LOD-46.9)	**65.7** (60.5-71.1)	**83.9** (74.9-92.9)	1871
Age group							
12-19 years	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	656
	01-02	†	†	†	†	†	†
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	586
20 years and older	99-00	*	**< LOD**	**< LOD**	**85.2** (<LOD-96.0)	**107** (98.3-125)	1239
	01-02	*	**< LOD**	**60.8** (51.3-70.6)	**99.4** (83.4-114)	**134** (113-152)	1230
	03-04	*	**< LOD**	**46.5** (<LOD-50.6)	**69.3** (62.2-74.6)	**86.8** (78.3-99.8)	1285
Gender							
Males	99-00	*	**< LOD**	**< LOD**	**< LOD**	**95.7** (80.1-101)	906
	01-02	*	**< LOD**	**62.7** (49.3-76.6)	**98.5** (76.6-134)	**135** (105-160)	560
	03-04	*	**< LOD**	**43.4** (<LOD-46.3)	**62.0** (56.8-71.9)	**83.2** (72.4-95.0)	920
Females	99-00	*	**< LOD**	**< LOD**	**90.0** (<LOD-101)	**111** (97.2-129)	989
	01-02	*	**< LOD**	**59.8** (52.0-67.6)	**100** (90.5-105)	**126** (107-146)	670
	03-04	*	**< LOD**	**< LOD**	**66.9** (59.7-74.3)	**84.4** (74.7-95.7)	951
Race/ethnicity							
Mexican Americans	99-00	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	632
	01-02	*	**< LOD**	**< LOD**	**55.8** (48.7-69.7)	**76.3** (61.9-92.4)	264
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**57.1** (<LOD-70.2)	423
Non-Hispanic blacks	99-00	*	**< LOD**	**< LOD**	**< LOD**	**105** (82.7-116)	400
	01-02	*	**< LOD**	**50.0** (41.3-60.4)	**89.5** (72.3-107)	**121** (92.0-154)	216
	03-04	*	**< LOD**	**< LOD**	**66.8** (48.5-93.2)	**97.4** (79.1-129)	454
Non-Hispanic whites	99-00	*	**< LOD**	**< LOD**	**< LOD**	**103** (96.8-122)	706
	01-02	*	**37.5** (<LOD-44.1)	**65.7** (52.9-78.2)	**104** (90.7-118)	**136** (118-154)	665
	03-04	*	**< LOD**	**45.9** (<LOD-50.6)	**68.3** (61.3-73.6)	**85.0** (74.6-102)	873

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,7,8-Tetrachlorodibenzofuran (TCDF) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1903
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	*	< LOD	< LOD	< LOD	< LOD	1868
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	586
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1243
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	*	< LOD	< LOD	< LOD	< LOD	1282
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	912
	01-02	*	< LOD	< LOD	< LOD	< LOD	558
	03-04	*	< LOD	< LOD	< LOD	< LOD	917
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	991
	01-02	*	< LOD	< LOD	< LOD	< LOD	671
	03-04	*	< LOD	< LOD	< LOD	< LOD	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	628
	01-02	*	< LOD	< LOD	< LOD	< LOD	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	217
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	707
	01-02	*	< LOD	< LOD	< LOD	< LOD	667
	03-04	*	< LOD	< LOD	< LOD	< LOD	870

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 11.9, 5.2, and 6.0, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,7,8-Tetrachlorodibenzofuran (TCDF) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1903
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	*	< LOD	< LOD	< LOD	< LOD	1868
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	660
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	586
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1243
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	*	< LOD	< LOD	< LOD	< LOD	1282
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	912
	01-02	*	< LOD	< LOD	< LOD	< LOD	558
	03-04	*	< LOD	< LOD	< LOD	< LOD	917
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	991
	01-02	*	< LOD	< LOD	< LOD	< LOD	671
	03-04	*	< LOD	< LOD	< LOD	< LOD	951
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	628
	01-02	*	< LOD	< LOD	< LOD	< LOD	262
	03-04	*	< LOD	< LOD	< LOD	< LOD	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	217
	03-04	*	< LOD	< LOD	< LOD	< LOD	454
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	707
	01-02	*	< LOD	< LOD	< LOD	< LOD	667
	03-04	*	< LOD	< LOD	< LOD	< LOD	870

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 3,4,4',5-Tetrachlorobiphenyl (PCB 81) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1883
	01-02	*	< LOD	< LOD	< LOD	< LOD	1215
	03-04	*	< LOD	< LOD	< LOD	13.4 (<LOD-16.4)	1860
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	651
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	14.7 (<LOD-16.5)	579
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1232
	01-02	*	< LOD	< LOD	< LOD	< LOD	1215
	03-04	*	< LOD	< LOD	< LOD	13.1 (<LOD-16.5)	1281
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	900
	01-02	*	< LOD	< LOD	< LOD	< LOD	554
	03-04	*	< LOD	< LOD	< LOD	14.4 (<LOD-17.9)	913
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	983
	01-02	*	< LOD	< LOD	< LOD	< LOD	661
	03-04	*	< LOD	< LOD	< LOD	< LOD	947
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	621
	01-02	*	< LOD	< LOD	< LOD	< LOD	259
	03-04	*	< LOD	< LOD	< LOD	18.7 (<LOD-25.2)	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	405
	01-02	*	< LOD	< LOD	< LOD	< LOD	218
	03-04	*	< LOD	< LOD	< LOD	< LOD	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	699
	01-02	*	< LOD	< LOD	< LOD	< LOD	657
	03-04	*	< LOD	< LOD	< LOD	13.1 (<LOD-16.4)	867

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 68.4, 26.8, and 13.1, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 3,4,4',5-Tetrachlorobiphenyl (PCB 81) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1883
	01-02	*	< LOD	< LOD	< LOD	< LOD	1215
	03-04	*	< LOD	< LOD	< LOD	80.3 (<LOD-96.2)	1860
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	651
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	71.4 (<LOD-82.8)	579
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1232
	01-02	*	< LOD	< LOD	< LOD	< LOD	1215
	03-04	*	< LOD	< LOD	< LOD	80.7 (<LOD-99.3)	1281
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	900
	01-02	*	< LOD	< LOD	< LOD	< LOD	554
	03-04	*	< LOD	< LOD	< LOD	81.1 (<LOD-104)	913
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	983
	01-02	*	< LOD	< LOD	< LOD	< LOD	661
	03-04	*	< LOD	< LOD	< LOD	< LOD	947
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	621
	01-02	*	< LOD	< LOD	< LOD	< LOD	259
	03-04	*	< LOD	< LOD	< LOD	103 (<LOD-199)	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	405
	01-02	*	< LOD	< LOD	< LOD	< LOD	218
	03-04	*	< LOD	< LOD	< LOD	< LOD	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	699
	01-02	*	< LOD	< LOD	< LOD	< LOD	657
	03-04	*	< LOD	< LOD	< LOD	80.5 (<LOD-106)	867

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**28.5** (24.9-32.8)	**53.2** (45.7-59.9)	**80.5** (62.8-100)	1896
	01-02	**22.7** (20.9-24.7)	**24.5** (22.2-26.8)	**40.8** (36.1-47.5)	**69.3** (61.6-80.8)	**108** (92.7-116)	1226
	03-04	**16.3** (14.9-17.9)	**14.7** (<LOD-16.5)	**24.8** (22.4-27.4)	**46.7** (41.6-51.9)	**68.7** (58.1-84.4)	1860
Age group							
12-19 years	99-00	*	< LOD	< LOD	**24.3** (<LOD-27.5)	**31.1** (26.4-36.4)	658
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	**17.0** (15.2-20.2)	**21.2** (17.3-25.6)	577
20 years and older	99-00	*	< LOD	**30.8** (27.2-36.3)	**57.1** (50.5-65.8)	**89.5** (66.1-110)	1238
	01-02	**22.7** (20.9-24.7)	**24.5** (22.2-26.8)	**40.8** (36.1-47.5)	**69.3** (61.6-80.8)	**108** (92.7-116)	1226
	03-04	**17.6** (16.0-19.3)	**16.0** (14.2-18.6)	**26.8** (24.2-30.3)	**49.8** (43.5-59.1)	**74.8** (60.2-94.4)	1283
Gender							
Males	99-00	*	< LOD	**25.8** (<LOD-28.9)	**41.6** (36.1-45.7)	**62.0** (49.7-75.0)	911
	01-02	**20.3** (18.5-22.3)	**23.1** (20.8-25.4)	**36.6** (32.8-39.4)	**52.7** (46.4-62.3)	**81.9** (61.0-101)	561
	03-04	**14.9** (<LOD-16.4)	< LOD	**21.8** (20.1-25.4)	**38.5** (31.0-46.1)	**51.5** (46.5-60.5)	912
Females	99-00	*	< LOD	**33.6** (27.4-41.4)	**59.4** (53.0-78.7)	**98.1** (69.9-120)	985
	01-02	**25.1** (22.9-27.4)	**26.1** (23.0-28.8)	**48.6** (41.4-54.4)	**82.9** (71.1-96.8)	**116** (98.6-128)	665
	03-04	**17.8** (16.0-19.7)	**15.7** (<LOD-18.4)	**27.6** (24.3-33.4)	**57.1** (46.0-67.1)	**82.5** (63.0-109)	948
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**23.8** (<LOD-30.3)	**43.2** (37.0-52.6)	**66.1** (52.4-79.2)	631
	01-02	**17.8** (15.5-20.4)	**19.9** (18.3-21.2)	**28.5** (26.5-34.2)	**47.9** (39.7-54.9)	**69.2** (49.3-103)	262
	03-04	**15.5** (<LOD-17.9)	**14.2** (<LOD-17.5)	**22.5** (18.9-26.8)	**31.2** (27.4-37.8)	**42.0** (33.5-48.0)	420
Non-Hispanic blacks	99-00	*	< LOD	**30.6** (25.2-43.1)	**67.4** (45.0-126)	**126** (67.4-224)	404
	01-02	**22.2** (18.2-27.0)	**22.1** (19.6-25.4)	**44.3** (37.9-51.5)	**88.4** (59.0-111)	**115** (96.1-153)	217
	03-04	**16.5** (13.9-19.5)	< LOD	**23.5** (18.9-34.6)	**63.4** (41.5-126)	**142** (52.1-292)	452
Non-Hispanic whites	99-00	*	< LOD	**28.3** (<LOD-34.0)	**50.5** (41.6-57.0)	**67.8** (57.0-94.1)	704
	01-02	**23.1** (20.9-25.4)	**24.7** (22.0-27.6)	**42.0** (35.4-49.6)	**72.3** (63.9-82.9)	**114** (91.0-128)	663
	03-04	**16.0** (14.3-17.8)	**14.5** (<LOD-16.9)	**24.3** (21.4-28.2)	**46.5** (41.6-50.9)	**64.0** (52.1-76.1)	869

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 23.2, 10.8, and 13.9, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 3,3',4,4',5-Pentachlorobiphenyl (PCB 126) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**177** (151-212)	**336** (294-404)	**564** (455-663)	1896
	01-02	**147** (135-160)	**158** (143-175)	**270** (249-298)	**482** (436-541)	**738** (625-840)	1226
	03-04	**100** (91.0-110)	**89.8** (<LOD-101)	**159** (146-178)	**308** (273-349)	**475** (378-590)	1860
Age group							
12-19 years	99-00	*	< LOD	< LOD	**108** (<LOD-126)	**144** (116-196)	658
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	**88.2** (78.8-106)	**109** (89.2-135)	577
20 years and older	99-00	*	< LOD	**204** (173-232)	**381** (319-451)	**596** (479-709)	1238
	01-02	**147** (135-160)	**158** (143-175)	**270** (249-298)	**482** (436-541)	**738** (625-840)	1226
	03-04	**111** (100-122)	**100** (88.7-115)	**176** (158-194)	**326** (286-394)	**534** (394-668)	1283
Gender							
Males	99-00	*	< LOD	**154** (<LOD182)	**260** (241-274)	**382** (308-509)	911
	01-02	**134** (121-149)	**152** (130-169)	**249** (233-267)	**399** (346-467)	**566** (467-693)	561
	03-04	**92.3** (<LOD-102)	< LOD	**148** (131-168)	**245** (203-296)	**360** (296-442)	912
Females	99-00	*	< LOD	**212** (159-250)	**429** (350-531)	**648** (534-744)	985
	01-02	**159** (146-172)	**160** (149-186)	**301** (270-348)	**550** (483-637)	**818** (658-958)	665
	03-04	**108** (96.2-121)	**94.5** (<LOD-110)	**180** (153-212)	**370** (303-455)	**559** (438-843)	948
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	**146** (<LOD213)	**285** (229-364)	**424** (361-534)	631
	01-02	**114** (97.8-133)	**125** (106-150)	**217** (175-257)	**335** (272-460)	**593** (354-784)	262
	03-04	**95.3** (<LOD-111)	**91.4** (<LOD-99.4)	**145** (116-180)	**238** (172-288)	**298** (238-461)	420
Non-Hispanic blacks	99-00	*	< LOD	**192** (147-258)	**457** (308-691)	**786** (457-1520)	404
	01-02	**131** (106-161)	**128** (110-158)	**266** (214-304)	**532** (361-662)	**779** (585-1060)	217
	03-04	**94.3** (79.0-112)	< LOD	**143** (106-254)	**483** (254-847)	**976** (483-1430)	452
Non-Hispanic whites	99-00	*	< LOD	**175** (<LOD215)	**311** (274-356)	**508** (394-660)	704
	01-02	**150** (136-164)	**160** (146-179)	**276** (249-301)	**486** (431-553)	**746** (600-937)	663
	03-04	**98.4** (87.5-111)	**89.4** (<LOD-104)	**158** (142-182)	**297** (260-346)	**431** (365-541)	869

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in pg/g lipid or parts per trillion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**34.4** (31.0-38.7)	**44.9** (40.6-48.9)	1888
	01-02	**17.9** (16.0-19.9)	**19.0** (17.0-22.0)	**33.1** (27.7-38.6)	**50.0** (43.9-55.0)	**60.9** (56.1-65.8)	1223
	03-04	*	< LOD	**19.5** (16.8-22.7)	**31.0** (27.9-36.0)	**40.6** (36.5-47.3)	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	648
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	581
20 years and older	99-00	*	< LOD	< LOD	**36.4** (33.8-40.3)	**47.8** (42.8-51.0)	1240
	01-02	**17.9** (16.0-19.9)	**19.0** (17.0-22.0)	**33.1** (27.7-38.6)	**50.0** (43.9-55.0)	**60.9** (56.1-65.8)	1223
	03-04	*	< LOD	**21.9** (19.0-24.2)	**32.7** (28.6-37.3)	**43.2** (37.3-49.5)	1285
Gender							
Males	99-00	*	< LOD	< LOD	**36.2** (31.9-40.1)	**44.3** (39.0-51.3)	908
	01-02	**20.2** (17.8-22.8)	**22.1** (18.5-25.3)	**36.0** (29.5-43.2)	**53.7** (46.5-57.3)	**60.9** (55.7-69.0)	559
	03-04	*	< LOD	**22.3** (17.7-24.8)	**36.3** (29.3-41.1)	**46.1** (38.8-52.0)	917
Females	99-00	*	< LOD	< LOD	**34.0** (29.4-38.6)	**46.5** (37.9-51.1)	980
	01-02	**16.0** (14.2-18.1)	**17.0** (14.7-19.2)	**30.2** (24.5-36.5)	**46.4** (40.7-51.9)	**60.9** (52.2-70.0)	664
	03-04	*	< LOD	**18.4** (<LOD-20.4)	**28.4** (27.2-30.6)	**35.8** (31.0-41.1)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**31.9** (28.8-35.2)	622
	01-02	*	< LOD	**15.0** (11.3-18.3)	**25.4** (18.3-32.3)	**32.5** (26.7-41.9)	260
	03-04	*	< LOD	< LOD	< LOD	**20.9** (16.5-30.2)	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**40.3** (28.7-48.6)	**52.2** (44.3-63.6)	403
	01-02	**17.2** (15.4-19.1)	**18.5** (15.7-20.0)	**31.7** (25.8-35.4)	**47.5** (42.0-54.0)	**57.3** (48.3-64.5)	217
	03-04	*	< LOD	**17.3** (<LOD-22.6)	**31.5** (26.8-36.9)	**58.7** (31.5-97.9)	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	**34.6** (31.7-40.1)	**45.3** (40.1-50.9)	709
	01-02	**19.5** (17.2-22.2)	**21.4** (17.4-24.7)	**36.0** (29.8-41.1)	**53.5** (47.0-58.3)	**64.3** (59.2-72.8)	662
	03-04	*	< LOD	**21.2** (17.4-24.5)	**32.6** (27.3-38.8)	**41.1** (35.9-50.2)	873

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 27.0, 11.0, and 15.9, respectively.
† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in fg/g of serum or parts per quadrillion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**230** (219-244)	**287** (274-319)	1888
	01-02	**115** (103-129)	**125** (108-146)	**217** (189-253)	**344** (300-376)	**416** (379-490)	1223
	03-04	*	< LOD	**133** (114-149)	**203** (191-226)	**269** (243-305)	1866
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	648
	01-02	†	†	†	†	†	†
	03-04	*	< LOD	< LOD	< LOD	< LOD	581
20 years and older	99-00	*	< LOD	< LOD	**241** (227-261)	**303** (281-339)	1240
	01-02	**115** (103-129)	**125** (108-146)	**217** (189-253)	**344** (300-376)	**416** (379-490)	1223
	03-04	*	< LOD	**146** (130-160)	**216** (198-242)	**287** (245-325)	1285
Gender							
Males	99-00	*	< LOD	< LOD	**229** (215-258)	**286** (256-338)	908
	01-02	**133** (117-152)	**151** (130-168)	**244** (198-293)	**363** (309-409)	**449** (372-529)	559
	03-04	*	< LOD	**143** (122-159)	**225** (190-259)	**291** (245-334)	917
Females	99-00	*	< LOD	< LOD	**234** (197-257)	**293** (261-346)	980
	01-02	**102** (90.0-115)	**107** (91.0-123)	**195** (170-234)	**319** (282-368)	**402** (373-462)	664
	03-04	*	< LOD	**120** (<LOD140)	**194** (182-203)	**249** (222-284)	949
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	**215** (181-261)	622
	01-02	*	< LOD	**98.1** (79.3-138)	**184** (143-250)	**266** (179-341)	260
	03-04	*	< LOD	< LOD	< LOD	**168** (109-237)	420
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**251** (190-299)	**320** (262-410)	403
	01-02	**101** (91.2-113)	**104** (88.0-118)	**190** (147-234)	**299** (267-335)	**362** (309-423)	217
	03-04	*	< LOD	**110** (<LOD-144)	**216** (162-257)	**338** (221-556)	453
Non-Hispanic whites	99-00	*	< LOD	< LOD	**238** (222-257)	**286** (267-340)	709
	01-02	**127** (112-144)	**145** (124-157)	**229** (195-275)	**368** (317-388)	**438** (388-515)	662
	03-04	*	< LOD	**141** (116-165)	**210** (189-242)	**277** (239-324)	873

† Data not collected for this age group for Survey year 01-02.
< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1915
	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	**1.20** (1.09-1.31)	**1.09** (1.00-1.20)	**1.90** (1.75-2.20)	**4.04** (3.40-4.89)	**6.24** (5.20-7.79)	1879
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	665
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.686** (.603-.781)	**.700** (.600-.720)	**1.00** (.900-1.11)	**1.50** (1.20-2.00)	**2.26** (1.50-3.50)	593
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1250
	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**1.30** (1.18-1.43)	**1.15** (1.04-1.30)	**2.10** (1.86-2.40)	**4.44** (3.80-5.20)	**6.82** (5.70-8.30)	1286
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	913
	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	**1.02** (.923-1.12)	**.980** (.850-1.08)	**1.60** (1.40-1.80)	**3.20** (2.76-3.42)	**4.70** (3.83-5.50)	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1002
	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**1.40** (1.25-1.57)	**1.20** (1.05-1.40)	**2.30** (2.00-2.79)	**5.17** (4.47-5.90)	**7.70** (6.00-9.55)	942
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	635
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.719** (.624-.829)	**.700** (.600-.800)	**1.10** (.900-1.36)	**1.90** (1.80-2.20)	**2.90** (1.98-3.52)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**12.8** (<LOD-18.0)	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**1.41** (1.15-1.74)	**1.14** (.980-1.32)	**2.47** (1.70-3.90)	**6.70** (4.09-10.1)	**11.9** (6.40-18.1)	456
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	714
	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**1.21** (1.08-1.36)	**1.10** (1.00-1.20)	**1.90** (1.74-2.28)	**3.91** (3.22-4.85)	**5.93** (4.98-7.79)	878

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4'-Pentachlorobiphenyl (PCB 105) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1915
	01-02	*	< LOD	< LOD	< LOD	< LOD	2307
	03-04	**.007** (.007-.008)	**.007** (.006-.007)	**.012** (.011-.014)	**.027** (.023-.031)	**.043** (.037-.049)	1879
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	665
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**.003** (.003-.004)	**.003** (.003-.004)	**.005** (.005-.006)	**.008** (.006-.010)	**.011** (.008-.020)	593
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1250
	01-02	*	< LOD	< LOD	< LOD	< LOD	1549
	03-04	**.008** (.007-.009)	**.007** (.006-.008)	**.014** (.012-.015)	**.030** (.026-.035)	**.047** (.039-.053)	1286
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	913
	01-02	*	< LOD	< LOD	< LOD	< LOD	1075
	03-04	**.006** (.006-.007)	**.006** (.005-.007)	**.010** (.009-.011)	**.019** (.016-.023)	**.030** (.027-.039)	937
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1002
	01-02	*	< LOD	< LOD	< LOD	< LOD	1232
	03-04	**.008** (.007-.010)	**.007** (.006-.009)	**.015** (.013-.017)	**.033** (.029-.040)	**.049** (.043-.067)	942
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	635
	01-02	*	< LOD	< LOD	< LOD	< LOD	567
	03-04	**.004** (.004-.005)	**.004** (.004-.005)	**.007** (.006-.009)	**.014** (.011-.017)	**.019** (.015-.023)	427
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	**.090** (<LOD-.110)	409
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.008** (.007-.010)	**.007** (.005-.008)	**.015** (.010-.020)	**.041** (.027-.067)	**.082** (.041-.116)	456
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	714
	01-02	*	< LOD	< LOD	< LOD	< LOD	1061
	03-04	**.007** (.007-.008)	**.007** (.006-.007)	**.012** (.011-.014)	**.027** (.022-.031)	**.043** (.035-.049)	878

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	**13.1** (<LOD-15.1)	**27.0** (22.1-30.3)	**40.8** (32.8-48.6)	1926
	01-02	*	< LOD	**15.1** (13.0-17.5)	**29.0** (26.1-33.7)	**44.6** (39.6-48.9)	2307
	03-04	**6.00** (5.54-6.50)	**5.19** (4.80-5.61)	**10.4** (9.70-11.6)	**21.8** (19.3-23.8)	**31.3** (28.2-36.6)	1887
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	**3.06** (2.76-3.39)	**2.83** (2.70-3.10)	**4.15** (3.60-4.56)	**6.80** (4.70-9.60)	**9.60** (6.80-13.2)	596
20 years and older	99-00	*	< LOD	**14.9** (12.9-17.4)	**28.1** (24.8-33.8)	**43.8** (35.6-52.3)	1259
	01-02	*	< LOD	**16.9** (15.1-19.0)	**32.4** (28.3-37.3)	**46.5** (41.1-51.0)	1549
	03-04	**6.62** (6.10-7.18)	**5.65** (5.21-6.40)	**11.5** (10.2-12.6)	**22.8** (20.7-25.9)	**34.3** (29.6-39.6)	1291
Gender							
Males	99-00	*	< LOD	< LOD	**19.6** (16.6-24.4)	**28.0** (24.4-38.1)	919
	01-02	*	< LOD	**12.0** (<LOD-14.9)	**22.0** (17.6-27.1)	**32.7** (25.4-47.5)	1075
	03-04	**5.11** (4.70-5.57)	**4.71** (4.16-5.06)	**8.72** (7.30-9.70)	**16.4** (14.0-18.9)	**23.2** (20.7-25.1)	940
Females	99-00	*	< LOD	**16.7** (13.6-19.7)	**32.0** (27.1-40.3)	**46.8** (41.2-57.8)	1007
	01-02	*	< LOD	**18.7** (16.5-21.0)	**36.4** (31.6-40.9)	**48.9** (44.5-54.3)	1232
	03-04	**6.99** (6.32-7.73)	**6.02** (5.31-6.84)	**12.3** (11.1-14.4)	**27.3** (22.7-30.0)	**37.8** (31.3-45.0)	947
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	**17.3** (14.5-19.6)	**23.7** (20.9-27.1)	636
	01-02	*	< LOD	< LOD	**16.8** (12.5-21.7)	**26.4** (19.3-33.2)	567
	03-04	**3.56** (3.04-4.18)	**3.15** (2.60-3.82)	**5.02** (4.26-6.66)	**9.37** (7.45-11.7)	**14.0** (10.0-17.6)	426
Non-Hispanic blacks	99-00	*	< LOD	**19.0** (13.6-21.7)	**38.7** (28.4-54.4)	**59.7** (45.7-80.8)	413
	01-02	*	< LOD	**15.6** (12.6-19.9)	**37.3** (26.1-46.4)	**54.9** (40.0-66.6)	515
	03-04	**6.70** (5.52-8.14)	**5.25** (4.40-6.10)	**12.7** (8.80-18.0)	**35.1** (21.1-45.0)	**57.8** (33.5-110)	462
Non-Hispanic whites	99-00	*	< LOD	**13.1** (<LOD-15.6)	**25.6** (20.8-32.0)	**40.3** (30.4-46.8)	720
	01-02	*	< LOD	**15.9** (13.6-18.1)	**31.1** (27.1-35.9)	**45.3** (38.7-50.1)	1061
	03-04	**6.19** (5.57-6.87)	**5.46** (4.85-6.20)	**10.9** (9.62-12.1)	**22.0** (19.3-24.4)	**30.7** (26.2-36.6)	878

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 10.5, and 0.6, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3',4,4',5-Pentachlorobiphenyl (PCB 118) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	.090 (<LOD-.100)	.180 (.150-.200)	.260 (.220-.320)	1926
	01-02	*	< LOD	.100 (.090-.110)	.190 (.160-.220)	.300 (.270-.320)	2307
	03-04	.037 (.034-.040)	.032 (.029-.036)	.066 (.061-.073)	.143 (.127-.160)	.216 (.192-.233)	1887
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	667
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	.015 (.014-.017)	.014 (.013-.016)	.021 (.018-.023)	.036 (.024-.046)	.047 (.035-.076)	596
20 years and older	99-00	*	< LOD	.100 (.090-.110)	.190 (.170-.220)	.280 (.230-.360)	1259
	01-02	*	< LOD	.110 (.100-.130)	.210 (.180-.250)	.310 (.280-.370)	1549
	03-04	.041 (.038-.045)	.036 (.032-.041)	.072 (.066-.081)	.159 (.137-.174)	.226 (.202-.249)	1291
Gender							
Males	99-00	*	< LOD	< LOD	.130 (.110-.140)	.190 (.160-.220)	919
	01-02	*	< LOD	.080 (<LOD-.100)	.140 (.120-.170)	.210 (.160-.300)	1075
	03-04	.032 (.029-.035)	.030 (.026-.033)	.054 (.046-.062)	.110 (.083-.125)	.160 (.136-.180)	940
Females	99-00	*	< LOD	.110 (.090-.130)	.210 (.180-.260)	.320 (.260-.410)	1007
	01-02	*	< LOD	.130 (.100-.140)	.240 (.210-.260)	.360 (.300-.380)	1232
	03-04	.042 (.038-.047)	.036 (.030-.043)	.081 (.068-.097)	.176 (.152-.206)	.242 (.217-.290)	947
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	.110 (.090-.130)	.140 (.130-.180)	636
	01-02	*	< LOD	< LOD	.120 (.080-.160)	.180 (.130-.220)	567
	03-04	.022 (.018-.026)	.019 (.016-.024)	.034 (.029-.039)	.069 (.046-.086)	.094 (.075-.117)	426
Non-Hispanic blacks	99-00	*	< LOD	.120 (.080-.150)	.220 (.180-.320)	.400 (.260-.500)	413
	01-02	*	< LOD	.100 (.070-.120)	.210 (.170-.270)	.320 (.230-.460)	515
	03-04	.038 (.031-.046)	.030 (.026-.034)	.074 (.054-.106)	.218 (.133-.277)	.370 (.218-.618)	462
Non-Hispanic whites	99-00	*	< LOD	.090 (<LOD-.100)	.180 (.150-.200)	.250 (.200-.330)	720
	01-02	*	< LOD	.100 (.090-.120)	.210 (.170-.240)	.300 (.270-.360)	1061
	03-04	.038 (.034-.043)	.034 (.029-.040)	.067 (.062-.076)	.143 (.127-.165)	.209 (.178-.234)	878

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	**12.6** (<LOD-13.8)	**17.0** (15.5-18.0)	1907
	01-02	*	< LOD	< LOD	**14.3** (12.1-16.0)	**18.3** (15.6-21.1)	2296
	03-04	**2.54** (2.36-2.74)	**3.29** (2.90-3.80)	**7.00** (6.20-8.07)	**11.4** (10.4-12.6)	**15.3** (13.8-17.5)	1880
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	665
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	**.500** (<LOD-.660)	**1.20** (1.00-1.43)	**2.30** (2.06-2.45)	**3.00** (2.37-3.60)	586
20 years and older	99-00	*	< LOD	< LOD	**13.6** (<LOD-14.7)	**17.5** (16.0-20.1)	1242
	01-02	*	< LOD	< LOD	**15.0** (13.3-17.0)	**19.7** (17.0-22.1)	1540
	03-04	**3.31** (3.05-3.60)	**4.10** (3.40-4.66)	**7.81** (6.80-8.70)	**12.0** (10.9-13.5)	**16.8** (14.7-18.6)	1294
Gender							
Males	99-00	*	< LOD	< LOD	**12.6** (<LOD-14.0)	**17.0** (14.6-18.0)	912
	01-02	*	< LOD	< LOD	**13.7** (11.3-16.4)	**18.4** (14.3-22.1)	1069
	03-04	**2.57** (2.34-2.82)	**3.10** (2.80-3.80)	**6.92** (5.82-8.00)	**11.8** (9.79-14.2)	**17.1** (14.7-19.3)	940
Females	99-00	*	< LOD	< LOD	**12.8** (<LOD-14.7)	**16.5** (15.4-20.7)	995
	01-02	*	< LOD	< LOD	**14.8** (13.2-15.5)	**18.2** (16.2-21.0)	1227
	03-04	**2.51** (2.28-2.76)	**3.42** (2.80-4.10)	**7.09** (6.35-8.10)	**11.1** (10.4-12.0)	**14.1** (12.7-16.8)	940
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	< LOD	< LOD	566
	03-04	**.858** (.640-1.15)	**1.00** (.700-1.40)	**2.48** (1.50-3.60)	**4.78** (4.00-5.68)	**6.40** (5.40-7.70)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	**14.6** (<LOD-20.5)	**23.1** (17.2-32.1)	412
	01-02	*	< LOD	< LOD	**15.5** (12.7-21.0)	**23.5** (16.4-31.4)	511
	03-04	**2.32** (1.87-2.89)	**3.04** (2.40-3.60)	**7.40** (5.48-9.80)	**14.7** (11.5-18.6)	**24.8** (15.0-33.0)	456
Non-Hispanic whites	99-00	*	< LOD	< LOD	**13.6** (<LOD-15.2)	**17.4** (16.0-18.9)	711
	01-02	*	< LOD	< LOD	**15.0** (13.2-17.5)	**19.4** (16.2-22.1)	1056
	03-04	**3.03** (2.70-3.39)	**4.03** (3.15-4.66)	**7.76** (6.51-8.79)	**11.7** (10.5-13.1)	**15.7** (13.5-18.5)	880

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	.090 (<LOD-.090)	.110 (.100-.130)	1907
	01-02	*	< LOD	< LOD	.100 (.080-.110)	.130 (.110-.140)	2296
	03-04	.016 (.014-.017)	.021 (.018-.024)	.048 (.041-.052)	.075 (.069-.085)	.103 (.094-.112)	1880
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	665
	01-02	*	< LOD	< LOD	< LOD	< LOD	756
	03-04	*	.003 (<LOD-.003)	.006 (.005-.007)	.012 (.011-.012)	.015 (.012-.018)	586
20 years and older	99-00	*	< LOD	< LOD	.090 (<LOD-.100)	.120 (.100-.140)	1242
	01-02	*	< LOD	< LOD	.100 (.090-.120)	.130 (.120-.140)	1540
	03-04	.021 (.019-.023)	.026 (.021-.030)	.051 (.045-.057)	.082 (.072-.093)	.109 (.098-.121)	1294
Gender							
Males	99-00	*	< LOD	< LOD	.090 (<LOD-.100)	.110 (.090-.130)	912
	01-02	*	< LOD	< LOD	.090 (.080-.120)	.120 (.110-.150)	1069
	03-04	.016 (.014-.018)	.021 (.017-.025)	.045 (.037-.054)	.076 (.068-.094)	.108 (.094-.123)	940
Females	99-00	*	< LOD	< LOD	.090 (<LOD-.090)	.110 (.090-.140)	995
	01-02	*	< LOD	< LOD	.100 (.090-.100)	.130 (.110-.140)	1227
	03-04	.015 (.014-.017)	.020 (.017-.025)	.049 (.044-.052)	.073 (.064-.085)	.101 (.089-.112)	940
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	631
	01-02	*	< LOD	< LOD	< LOD	< LOD	566
	03-04	.005 (.004-.007)	.007 (.004-.009)	.015 (.011-.022)	.036 (.025-.041)	.046 (.037-.070)	423
Non-Hispanic blacks	99-00	*	< LOD	< LOD	.090 (<LOD-.120)	.150 (.110-.190)	412
	01-02	*	< LOD	< LOD	.100 (.080-.130)	.150 (.100-.180)	511
	03-04	.013 (.010-.017)	.018 (.014-.022)	.044 (.032-.056)	.099 (.067-.127)	.166 (.108-.198)	456
Non-Hispanic whites	99-00	*	< LOD	< LOD	.090 (<LOD-.100)	.110 (.100-.130)	711
	01-02	*	< LOD	< LOD	.100 (.090-.120)	.130 (.120-.140)	1056
	03-04	.019 (.017-.021)	.025 (.020-.031)	.051 (.044-.057)	.078 (.069-.089)	.104 (.094-.119)	880

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1897
	01-02	*	< LOD	< LOD	< LOD	< LOD	2294
	03-04	**.605** (.554-.661)	**.800** (.700-.940)	**1.73** (1.47-1.93)	**2.80** (2.50-3.10)	**3.80** (3.36-4.30)	1858
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	654
	01-02	*	< LOD	< LOD	< LOD	< LOD	755
	03-04	*	< LOD	< LOD	**.690** (.540-.760)	**.980** (.750-1.12)	580
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1243
	01-02	*	< LOD	< LOD	< LOD	< LOD	1539
	03-04	**.743** (.675-.817)	**.980** (.800-1.10)	**1.88** (1.69-2.05)	**2.98** (2.68-3.30)	**3.97** (3.51-4.59)	1278
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	901
	01-02	*	< LOD	< LOD	< LOD	< LOD	1068
	03-04	**.594** (.541-.653)	**.750** (.700-.900)	**1.65** (1.38-1.88)	**2.90** (2.39-3.50)	**4.00** (3.57-4.87)	928
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	996
	01-02	*	< LOD	< LOD	< LOD	< LOD	1226
	03-04	**.615** (.552-.685)	**.890** (.700-1.00)	**1.79** (1.60-1.99)	**2.70** (2.50-2.91)	**3.40** (3.20-3.93)	930
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	622
	01-02	*	< LOD	< LOD	< LOD	< LOD	566
	03-04	*	< LOD	**.600** (<LOD-.820)	**1.12** (.960-1.32)	**1.59** (1.20-1.80)	422
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	405
	01-02	*	< LOD	< LOD	< LOD	< LOD	510
	03-04	**.568** (.488-.662)	**.720** (.600-.930)	**1.80** (1.39-2.26)	**3.55** (3.10-4.40)	**5.35** (3.60-8.80)	448
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	716
	01-02	*	< LOD	< LOD	< LOD	< LOD	1055
	03-04	**.713** (.635-.801)	**.980** (.760-1.12)	**1.81** (1.58-2.06)	**2.86** (2.54-3.27)	**3.80** (3.27-4.73)	869

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.5, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1897
	01-02	*	< LOD	< LOD	< LOD	< LOD	2294
	03-04	**.004** (.003-.004)	**.005** (.004-.006)	**.011** (.010-.013)	**.018** (.016-.021)	**.024** (.022-.027)	1858
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	654
	01-02	*	< LOD	< LOD	< LOD	< LOD	755
	03-04	*	< LOD	< LOD	**.004** (.003-.004)	**.005** (.004-.005)	580
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1243
	01-02	*	< LOD	< LOD	< LOD	< LOD	1539
	03-04	**.005** (.004-.005)	**.006** (.005-.007)	**.012** (.011-.014)	**.019** (.017-.022)	**.026** (.023-.031)	1278
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	901
	01-02	*	< LOD	< LOD	< LOD	< LOD	1068
	03-04	**.004** (.003-.004)	**.005** (.004-.006)	**.011** (.009-.012)	**.018** (.016-.022)	**.025** (.022-.027)	928
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	996
	01-02	*	< LOD	< LOD	< LOD	< LOD	1226
	03-04	**.004** (.003-.004)	**.005** (.004-.006)	**.012** (.010-.013)	**.017** (.016-.020)	**.024** (.021-.027)	930
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	622
	01-02	*	< LOD	< LOD	< LOD	< LOD	566
	03-04	*	< LOD	**.004** (<LOD-.006)	**.008** (.006-.009)	**.011** (.009-.014)	422
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	405
	01-02	*	< LOD	< LOD	< LOD	< LOD	510
	03-04	**.003** (.003-.004)	**.004** (.003-.006)	**.011** (.008-.014)	**.025** (.016-.031)	**.040** (.026-.050)	448
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	716
	01-02	*	< LOD	< LOD	< LOD	< LOD	1055
	03-04	**.004** (.004-.005)	**.006** (.005-.008)	**.012** (.010-.014)	**.018** (.016-.021)	**.025** (.022-.027)	869

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1908
	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	**.494** (.441-.553)	**.700** (.560-.800)	**1.60** (1.40-1.70)	**2.99** (2.74-3.36)	**4.10** (3.80-4.47)	1864
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	666
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	< LOD	**.640** (.500-.770)	**.870** (.700-1.10)	584
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1242
	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	**.592** (.521-.673)	**.860** (.700-1.00)	**1.72** (1.55-2.03)	**3.30** (2.90-3.60)	**4.30** (3.90-4.81)	1280
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	908
	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.423** (<LOD-.471)	**.500** (.440-.600)	**1.33** (1.16-1.60)	**2.70** (2.25-3.50)	**3.80** (3.50-4.70)	931
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1000
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	**.573** (.492-.669)	**.880** (.660-1.06)	**1.71** (1.51-2.10)	**3.21** (2.82-3.62)	**4.30** (3.80-4.70)	933
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	627
	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	*	< LOD	**.600** (.400-.800)	**1.20** (.960-1.44)	**1.70** (1.30-1.94)	419
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	411
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.521** (.432-.628)	**.560** (.460-.800)	**1.95** (1.25-2.40)	**4.30** (3.27-6.79)	**7.90** (4.70-11.8)	451
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	715
	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	**.538** (.458-.632)	**.800** (.600-.990)	**1.66** (1.42-1.90)	**2.98** (2.70-3.45)	**3.94** (3.62-4.47)	875

Limit of detection (LOD, see Data Analysis section) for Survey years 99-00, 01-02, and 03-04 are 12.4, 10.5, and 0.4, respectively.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	99-00	*	< LOD	< LOD	< LOD	< LOD	1908
	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	**.003** (.003-.003)	**.004** (.003-.005)	**.010** (.009-.012)	**.020** (.018-.022)	**.026** (.024-.027)	1864
Age group							
12-19 years	99-00	*	< LOD	< LOD	< LOD	< LOD	666
	01-02	*	< LOD	< LOD	< LOD	< LOD	758
	03-04	*	< LOD	< LOD	**.004** (.003-.004)	**.005** (.004-.005)	584
20 years and older	99-00	*	< LOD	< LOD	< LOD	< LOD	1242
	01-02	*	< LOD	< LOD	< LOD	< LOD	1540
	03-04	**.004** (.003-.004)	**.005** (.004-.006)	**.012** (.010-.013)	**.021** (.019-.023)	**.027** (.025-.030)	1280
Gender							
Males	99-00	*	< LOD	< LOD	< LOD	< LOD	908
	01-02	*	< LOD	< LOD	< LOD	< LOD	1069
	03-04	**.003** (<LOD-.003)	**.003** (.003-.004)	**.009** (.008-.010)	**.018** (.015-.021)	**.023** (.021-.026)	931
Females	99-00	*	< LOD	< LOD	< LOD	< LOD	1000
	01-02	*	< LOD	< LOD	< LOD	< LOD	1229
	03-04	**.003** (.003-.004)	**.005** (.004-.006)	**.012** (.010-.013)	**.022** (.019-.024)	**.027** (.025-.031)	933
Race/ethnicity							
Mexican Americans	99-00	*	< LOD	< LOD	< LOD	< LOD	627
	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	*	< LOD	**.004** (.003-.004)	**.009** (.007-.011)	**.013** (.010-.015)	419
Non-Hispanic blacks	99-00	*	< LOD	< LOD	< LOD	< LOD	411
	01-02	*	< LOD	< LOD	< LOD	< LOD	515
	03-04	**.003** (.002-.004)	**.003** (.003-.005)	**.012** (.008-.015)	**.028** (.019-.042)	**.051** (.030-.072)	451
Non-Hispanic whites	99-00	*	< LOD	< LOD	< LOD	< LOD	715
	01-02	*	< LOD	< LOD	< LOD	< LOD	1056
	03-04	**.003** (.003-.004)	**.005** (.004-.006)	**.011** (.009-.013)	**.020** (.018-.022)	**.025** (.023-.027)	875

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3’,4,4’,5,5’-Heptachlorobiphenyl (PCB 189) (lipid adjusted)

Geometric mean and selected percentiles of serum concentrations (in ng/g of lipid or parts per billion on a lipid-weight basis) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	2298
	03-04	*	**< LOD**	**< LOD**	**.900** (.700-1.16)	**1.47** (1.10-2.18)	1817
Age group							
12-19 years	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	752
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**1.00** (<LOD-3.09)	570
20 years and older	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1546
	03-04	*	**< LOD**	**< LOD**	**1.00** (.760-1.20)	**1.50** (1.10-2.14)	1247
Gender							
Males	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1070
	03-04	*	**< LOD**	**< LOD**	**1.00** (.800-1.20)	**1.54** (1.20-2.23)	903
Females	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1228
	03-04	*	**< LOD**	**< LOD**	**.830** (.600-1.14)	**1.39** (.890-2.18)	914
Race/ethnicity							
Mexican Americans	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	564
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**.700** (<LOD-1.00)	406
Non-Hispanic blacks	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	514
	03-04	*	**< LOD**	**< LOD**	**1.20** (.840-1.60)	**1.85** (1.20-2.83)	444
Non-Hispanic whites	01-02	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1057
	03-04	*	**< LOD**	**< LOD**	**.900** (.700-1.26)	**1.51** (1.04-2.19)	851

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 10.5 and 0.4.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Serum 2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189) (whole weight)

Geometric mean and selected percentiles of serum concentrations (in ng/g of serum or parts per billion) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	2298
	03-04	*	< LOD	< LOD	.006 (.005-.008)	.010 (.007-.014)	1817
Age group							
12-19 years	01-02	*	< LOD	< LOD	< LOD	< LOD	752
	03-04	*	< LOD	< LOD	< LOD	.005 (<LOD-.017)	570
20 years and older	01-02	*	< LOD	< LOD	< LOD	< LOD	1546
	03-04	*	< LOD	< LOD	.006 (.005-.008)	.010 (.007-.014)	1247
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	1070
	03-04	*	< LOD	< LOD	.006 (.005-.009)	.011 (.008-.014)	903
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	1228
	03-04	*	< LOD	< LOD	.005 (.004-.008)	.009 (.006-.014)	914
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	564
	03-04	*	< LOD	< LOD	< LOD	.005 (<LOD-.007)	406
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	514
	03-04	*	< LOD	< LOD	.008 (.005-.010)	.012 (.007-.016)	444
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	1057
	03-04	*	< LOD	< LOD	.006 (.005-.008)	.010 (.007-.014)	851

< LOD means less than the limit of detection for the lipid adjusted serum level, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Polycyclic Aromatic Hydrocarbons

General Information

Polycyclic aromatic hydrocarbons (PAHs) are a class of more than 100 chemicals generally produced during the incomplete burning of organic materials, including coal, oil, gas, wood, garbage, and tobacco. PAHs are composed of up to six benzene rings fused together such that any two adjacent benzene rings share two carbon bonds. Examples include phenanthrenes, naphthalene, and pyrene. Important PAH sources include motor vehicle exhaust, residential and industrial heating sources, coal, crude oil and natural gas processing, waste incineration, and tobacco smoke. The emitted PAHs can form or bind to particles in the air, and particle size depends in part on the source of the PAHs. The smaller or fine particulates (e.g., PM2.5 or smaller) have higher concentrations of PAHs than the larger or coarse particulates (Bostrom et al., 2002; Rehwagen et al., 2005). Ambient air PAH concentrations show seasonal variation (IPCS, 1998; Rehwagen et al., 2005). Smoking, grilling, broiling, or other high temperature processing leads to PAH formation in meat and in other foods, as well. Uncooked foods and vegetables generally contain low levels of PAHs but can be contaminated by airborne particle deposition or growth in contaminated soil. With the exception of naphthalene, the PAHs described here are not produced commercially in the U.S.

Human exposure usually occurs to PAH mixtures rather than to individual chemicals, and PAH mixture composition varies with the combustion source and temperature (ATSDR, 1995). For persons without occupational exposure, important sources of PAHs include ambient air pollution (especially motor vehicle exhaust), smoke from wood or fossil fuels, tobacco smoke, and foods. PAH exposure can occur in workplaces where petroleum products are burned or coked, such as coke production, coal gasification and gas refining, iron or steel production, roofing tar and asphalt application, waste incineration, and aluminum smelting. Coal tar ointments containing PAHs are used to treat several inflammatory skin conditions.

PAHs are lipid soluble and can be absorbed through the skin, respiratory tract, and gastrointestinal tract. PAH metabolism is complex and occurs primarily in the liver, and to a lesser extent, in other tissues. PAH elimination occurs via urine and feces, and urinary metabolites are eliminated within a few days (Ramesh et al., 2004). PAHs and their urinary hydroxylated metabolites that are measured in this *Report* are shown in the table. The metabolic pathways and enzyme-inducing effects of specific PAHs, such as benz[a]pyrene, have been actively studied to elucidate cancer potential and causal mechanisms (Ramesh et al., 2004). Although immunologic, kidney and brain toxicity have been seen in animals after high doses were administered, it is unclear if similar effects may occur in humans. Lung, bladder, and skin cancers have been reported in occupational settings following high PAH exposures (Bosetti et al., 2007; Bostrom et al., 2002; Lloyd, 1971). Exposure to fine particulates has been associated with fetal growth retardation, respiratory disorders, and cardiovascular disease, but it is unknown whether PAHs contained within fine particulates are etiologic (ATSDR, 1995; Choi, 2006).

IARC classifies naphthalene as a possible human carcinogen. NTP determined that naphthalene is reasonably anticipated to be a human carcinogen. Many other PAHs are considered to be probable or possible human carcinogens. IARC and NTP have classified specific PAH-containing chemical mixtures (e.g., soot, coke oven emissions, coal tars and coal tar pitches) as human carcinogens. OSHA has developed

Polycyclic Aromatic Hydrocarbon Metabolites in this *Report*

Polycyclic Aromatic Hydrocarbon (CAS number)	**Urinary hydroxylated metabolite** (CAS number)
Fluorene (86-73-7)	2-Hydroxyfluorene (2443-58-5) 3-Hydroxyfluorene (6344-67-8) 9-Hydroxyfluorene (484-17-3)
Naphthalene (91-20-3)	1-Hydroxynapthalene (90-15-3) 2-Hydroxynapthalene (135-19-3)
Phenanthrene (85-01-8)	1-Hydroxyphenanthrene (2433-56-9) 2-Hydroxyphenanthrene 3-Hydroxyphenanthrene (605-87-8) 4-Hydroxyphenanthrene (7651-86-7)
Pyrene (129-00-0)	1-Hydroxypyrene (5315-79-7)

criteria on the allowable levels of these chemicals in the workplace.

Information about external exposure (i.e., environmental levels) and health effects is available in reviews (Bosetti et al., 2007; Bostrom et al., 2002; Brandt and Watson 2003) and from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Measurement of urinary metabolites reflects recent exposure to PAHs. Some of the parent PAHs can produce more than one measurable urinary metabolite, as shown in the Table. The hydroxylated metabolites of PAHs are excreted in human urine both as free hydroxylated metabolites and as hydroxylated metabolites conjugated to glucuronic acid and sulfate. Urine metabolite profiles can vary depending on the PAH source(s), but also have been found to vary between individuals experiencing similar exposures within the same workplace (Grimmer et al., 1997; Jacob and Seidel 2002).

Finding a measurable amount of one or more metabolites in the urine does not mean that the levels of the PAH metabolites or the parent PAH cause an adverse health effect. Biomonitoring studies of urinary PAHs provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of PAHs than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Fluorene

CAS No. 86-73-7

Fluorene can be an intermediate in several chemical processes, and it is used to form polyradicals for resins and in manufacturing dyestuffs. Fluorene is frequently detected in the vapor phase of various PAH emission sources, including coal tar pitch, petroleum refineries, diesel exhaust fumes, and tobacco smoke, where it is the second most abundant PAH (Ding et al., 2005). Fluorene is present in air particulates resulting from vehicle emissions and combustion of coal and petroleum-based fuels (Fang et al., 2006). IARC determined that fluorene was not classifiable with respect to human carcinogenicity.

Biomonitoring Information

Urinary levels of 2-hydroxyfluorene, 3-hydroxyfluorene, and 9-hydroxyfluorene reflect recent exposure. Mean levels of 2-hydroxyfluorene were significantly higher in Japanese smokers than non-smokers in one small study (Toriba et al., 2003). By comparison, geometric mean and median urinary 2-hydroxyfluorene levels in adults in this *Report* were similar to the mean levels in the smokers and somewhat higher than those in the non-smokers.

Finding a measurable amount of one or more urinary fluorene metabolites does not mean that the level causes an adverse health effect. Biomonitoring studies of urinary fluorene metabolites can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of fluorene than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 2-Hydroxyfluorene

Metabolite of Fluorene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**304** (262-354)	**280** (242-319)	**679** (561-815)	**1850** (1430-2190)	**2670** (2230-3130)	2521
Age group							
6-11 years	03-04	**209** (183-239)	**228** (189-259)	**341** (295-411)	**576** (423-728)	**763** (613-827)	338
12-19 years	03-04	**281** (245-321)	**292** (259-323)	**502** (445-601)	**1000** (753-1320)	**1480** (1320-1930)	707
20 years and older	03-04	**323** (272-383)	**290** (247-334)	**832** (653-1020)	**2090** (1680-2460)	**2920** (2410-3650)	1476
Gender							
Males	03-04	**385** (333-446)	**338** (300-415)	**900** (739-1150)	**2120** (1770-2450)	**2930** (2490-3390)	1213
Females	03-04	**243** (204-290)	**226** (184-269)	**490** (405-617)	**1400** (907-1930)	**2310** (1740-3070)	1308
Race/ethnicity							
Mexican Americans	03-04	**248** (215-286)	**235** (203-293)	**502** (412-580)	**1100** (771-1330)	**1640** (1250-2240)	629
Non-Hispanic blacks	03-04	**432** (361-516)	**381** (317-462)	**856** (702-1270)	**2200** (1830-2610)	**2960** (2350-4460)	684
Non-Hispanic whites	03-04	**308** (255-372)	**280** (233-332)	**728** (554-898)	**1940** (1540-2390)	**2920** (2400-3500)	1045

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 5.0.

Urinary 2-Hydroxyfluorene (creatinine corrected)

Metabolite of Fluorene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**286** (256-320)	**221** (200-249)	**495** (429-629)	**1510** (1150-1800)	**2070** (1850-2390)	2521
Age group							
6-11 years	03-04	**221** (199-246)	**217** (188-238)	**305** (270-356)	**462** (370-535)	**695** (465-807)	338
12-19 years	03-04	**213** (189-240)	**189** (172-211)	**310** (275-377)	**649** (512-778)	**937** (762-1320)	707
20 years and older	03-04	**310** (274-350)	**233** (203-269)	**659** (494-835)	**1730** (1420-1940)	**2310** (1930-2590)	1476
Gender							
Males	03-04	**302** (271-337)	**242** (218-272)	**635** (494-758)	**1510** (1200-1700)	**1940** (1700-2310)	1213
Females	03-04	**271** (235-314)	**208** (183-244)	**415** (352-521)	**1530** (991-1890)	**2220** (1730-2590)	1308
Race/ethnicity							
Mexican Americans	03-04	**224** (197-255)	**198** (178-227)	**370** (306-432)	**745** (562-1030)	**1200** (745-1730)	629
Non-Hispanic blacks	03-04	**308** (259-365)	**249** (210-305)	**609** (430-803)	**1430** (939-1870)	**1880** (1430-2500)	684
Non-Hispanic whites	03-04	**304** (266-349)	**226** (199-261)	**581** (449-796)	**1630** (1410-1940)	**2310** (1940-2540)	1045

Urinary 3-Hydroxyfluorene

Metabolite of Fluorene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**134** (115-155)	**111** (96.0-126)	**253** (207-349)	**959** (666-1300)	**1620** (1390-1900)	2745
	03-04	**126** (108-148)	**103** (90.4-118)	**302** (231-404)	**1090** (934-1270)	**1740** (1400-2070)	2502
Age group							
6-11 years	01-02	**106** (94.8-119)	**106** (91.0-124)	**174** (145-200)	**287** (235-358)	**385** (306-455)	387
	03-04	**89.2** (77.3-103)	**92.3** (79.7-103)	**151** (113-172)	**238** (184-331)	**343** (241-423)	336
12-19 years	01-02	**129** (103-161)	**113** (97.0-137)	**222** (177-266)	**542** (325-1070)	**1210** (680-2130)	733
	03-04	**116** (100-134)	**114** (94.7-133)	**214** (181-269)	**476** (317-748)	**924** (609-1410)	701
20 years and older	01-02	**138** (119-161)	**111** (94.0-129)	**311** (228-429)	**1130** (823-1400)	**1850** (1470-2080)	1625
	03-04	**134** (112-160)	**105** (86.5-125)	**408** (300-537)	**1240** (1050-1480)	**1910** (1620-2290)	1465
Gender							
Males	01-02	**163** (137-194)	**134** (115-155)	**352** (242-481)	**1110** (721-1500)	**1850** (1390-2190)	1346
	03-04	**165** (140-194)	**133** (108-162)	**458** (313-681)	**1270** (1030-1530)	**1920** (1580-2120)	1205
Females	01-02	**111** (95.0-130)	**94.0** (83.0-108)	**204** (169-250)	**796** (498-1040)	**1390** (1250-1670)	1399
	03-04	**98.2** (81.2-119)	**80.5** (66.7-101)	**195** (163-272)	**842** (530-1200)	**1590** (1180-1800)	1297
Race/ethnicity							
Mexican Americans	01-02	**108** (87.1-134)	**99.0** (81.0-119)	**190** (144-255)	**476** (302-641)	**718** (476-1140)	662
	03-04	**93.4** (79.6-110)	**83.4** (67.0-96.9)	**190** (150-252)	**520** (388-726)	**1030** (688-1320)	622
Non-Hispanic blacks	01-02	**203** (169-244)	**162** (135-188)	**449** (308-830)	**1420** (1130-1780)	**2350** (1520-3000)	692
	03-04	**195** (157-242)	**160** (124-187)	**482** (303-827)	**1460** (1070-1800)	**2110** (1580-2830)	683
Non-Hispanic whites	01-02	**130** (108-157)	**108** (93.0-127)	**246** (202-352)	**948** (621-1320)	**1620** (1320-1990)	1207
	03-04	**129** (106-155)	**105** (87.6-124)	**313** (237-464)	**1200** (1010-1410)	**1870** (1430-2220)	1035

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 2.0 and 5.0.

Urinary 3-Hydroxyfluorene (creatinine corrected)

Metabolite of Fluorene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**125** (108-144)	**94.4** (83.3-106)	**220** (174-303)	**754** (622-873)	**1060** (909-1290)	2745
	03-04	**119** (106-134)	**86.6** (76.8-97.3)	**256** (201-337)	**856** (668-1060)	**1330** (1130-1590)	2502
Age group							
6-11 years	01-02	**119** (103-137)	**110** (96.7-121)	**153** (135-197)	**265** (206-377)	**382** (254-631)	387
	03-04	**94.6** (84.3-106)	**92.4** (83.1-98.5)	**130** (115-154)	**202** (168-282)	**311** (197-435)	336
12-19 years	01-02	**99.3** (81.6-121)	**81.9** (74.2-92.6)	**144** (109-197)	**390** (214-700)	**711** (372-1380)	733
	03-04	**88.1** (78.0-99.6)	**79.0** (72.5-83.2)	**137** (114-170)	**319** (225-440)	**586** (356-880)	701
20 years and older	01-02	**131** (113-151)	**94.4** (81.0-108)	**279** (195-367)	**862** (727-923)	**1210** (1010-1350)	1625
	03-04	**128** (113-146)	**88.2** (76.8-104)	**364** (242-484)	**1020** (828-1240)	**1500** (1290-1710)	1465
Gender							
Males	01-02	**132** (111-156)	**100** (88.5-117)	**260** (194-361)	**745** (560-914)	**1130** (862-1380)	1346
	03-04	**129** (114-147)	**95.8** (82.5-111)	**338** (226-456)	**833** (672-1010)	**1220** (980-1510)	1205
Females	01-02	**119** (104-136)	**88.9** (78.6-103)	**179** (156-227)	**777** (604-888)	**1030** (923-1270)	1399
	03-04	**110** (93.4-129)	**81.7** (69.5-91.5)	**183** (132-285)	**920** (488-1270)	**1460** (1130-1750)	1297
Race/ethnicity							
Mexican Americans	01-02	**101** (84.2-121)	**84.0** (74.8-97.2)	**159** (124-214)	**364** (227-598)	**604** (357-1230)	662
	03-04	**84.8** (73.1-98.4)	**68.8** (60.0-80.2)	**170** (119-213)	**353** (319-435)	**668** (353-1050)	622
Non-Hispanic blacks	01-02	**143** (118-173)	**110** (90.7-133)	**316** (186-525)	**849** (622-1230)	**1240** (882-1430)	692
	03-04	**139** (113-169)	**106** (93.1-118)	**328** (211-488)	**961** (580-1310)	**1310** (961-1770)	683
Non-Hispanic whites	01-02	**128** (108-152)	**94.7** (83.4-109)	**223** (171-323)	**816** (642-914)	**1150** (910-1410)	1207
	03-04	**127** (110-146)	**89.8** (79.1-104)	**311** (212-418)	**980** (768-1180)	**1460** (1270-1700)	1035

Urinary 9-Hydroxyfluorene

Metabolite of Fluorene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**267** (234-305)	**269** (233-313)	**541** (463-620)	**929** (839-1060)	**1390** (1130-1600)	2504
Age group							
6-11 years	03-04	**209** (184-238)	**216** (173-240)	**331** (267-458)	**594** (446-809)	**853** (553-1500)	333
12-19 years	03-04	**253** (216-297)	**271** (215-324)	**506** (413-560)	**894** (773-988)	**1210** (929-1510)	698
20 years and older	03-04	**277** (240-320)	**279** (237-335)	**583** (476-656)	**979** (842-1140)	**1490** (1140-1770)	1473
Gender							
Males	03-04	**330** (291-374)	**330** (285-372)	**632** (583-709)	**1090** (898-1370)	**1720** (1360-2250)	1208
Females	03-04	**218** (188-253)	**226** (191-253)	**439** (357-521)	**833** (697-973)	**1100** (955-1310)	1296
Race/ethnicity							
Mexican Americans	03-04	**229** (200-261)	**232** (197-274)	**435** (362-492)	**773** (561-1010)	**1030** (849-1170)	614
Non-Hispanic blacks	03-04	**380** (311-465)	**357** (291-475)	**709** (559-825)	**1260** (1080-1600)	**1880** (1560-2330)	679
Non-Hispanic whites	03-04	**266** (226-313)	**266** (228-324)	**558** (453-659)	**939** (824-1130)	**1450** (1090-1770)	1048

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 5.0.

Urinary 9-Hydroxyfluorene (creatinine corrected)

Metabolite of Fluorene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
T	03-04	**252** (230-276)	**233** (205-266)	**412** (371-461)	**729** (609-905)	**1100** (918-1390)	2504
A							
6	03-04	**223** (200-247)	**208** (176-264)	**343** (299-389)	**548** (433-689)	**866** (533-958)	333
1	03-04	**192** (172-215)	**182** (161-200)	**323** (286-360)	**484** (412-696)	**738** (571-1110)	698
2	03-04	**267** (242-294)	**243** (219-280)	**446** (392-490)	**788** (641-994)	**1280** (991-1560)	1473
G							
M	03-04	**260** (238-283)	**236** (209-269)	**429** (382-480)	**739** (591-952)	**1300** (916-1800)	1208
F	03-04	**244** (217-275)	**227** (198-269)	**396** (342-467)	**717** (569-905)	**1020** (905-1280)	1296
R							
M	03-04	**209** (188-232)	**195** (181-209)	**335** (293-379)	**541** (447-722)	**793** (569-1440)	614
N	03-04	**272** (226-326)	**258** (208-307)	**463** (349-568)	**777** (628-920)	**1040** (863-1300)	679
N	03-04	**263** (235-295)	**244** (211-287)	**439** (387-490)	**773** (607-1020)	**1290** (967-1700)	1048

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Naphthalene

CAS No. 91-20-3

Naphthalene is produced commercially from coal tar and petroleum. It is used in producing an assortment of chemicals: phthalate plasticizers, naphthalene sulfonates and dyes, the insecticide carbaryl, and synthetic leather tanning chemicals. Naphthalene is an intermediate in manufacturing several pharmaceuticals. Crystalline naphthalene has been used as a moth repellent. Naphthalene is the most abundant PAH in cigarette smoke (Ding et al., 2005), and it is present in fossil fuel smoke and exhaust fumes, especially from diesel and jet fuels. Non-occupational exposure typically occurs through inhaling ambient and indoor air, and cigarette smoke. Naphthalene can be absorbed through the skin as a result of handling moth repellent or wearing clothes stored with moth repellent. Workers may be exposed via inhalation or dermal absorption in settings such as naphthalene production, coal coking operations, and wood treatment with creosote.

In the body, naphthalene metabolism is complex, leading to biologically reactive metabolites and other metabolites that are excreted in the urine. In studies of workers, naphthalene air concentrations were correlated with 1- and 2-hydroxynaphthalene urine concentrations (Bieniek 1994; 1997). Both naphthalene and the insecticide carbaryl are metabolized to 1-hydroxynaphthalene, making it difficult to distinguish between these exposures in the general population (Meeker et al., 2007). In contrast, only naphthalene metabolism results in 2-hydroxynaphthalene in urine.

Humans can develop hemolytic anemia and jaundice after high dose naphthalene exposure by either inhalation or ingestion, or from skin exposure to clothing and bedding treated with naphthalene moth repellents (ATSDR, 2005). Exposure to naphthalene vapor can irritate the eyes and respiratory tract. High dose and chronic exposure in occupational settings can result in cataracts or lens opacities (ATSDR, 2005). OSHA has established a workplace standard. IARC considers naphthalene to be a possible human carcinogen, and NTP considers that it is reasonably anticipated to be a human carcinogen.

Biomonitoring Information

Urinary levels of 1-hydroxynaphthalene and 2-hydroxynaphthalene (1-naphthol and 2-naphthol, respectively) reflect recent exposure. Levels similar to those reported in NHANES 2001-2002 and 2003-2004 subsamples have been found in small studies of pre-school children, adolescents and non-occupationally exposed adults (Kang et al., 2002; Kim et al., 2003; Kuusimaki et al., 2004; Wilson et al., 2003). Smokers typically have urinary 1- and 2-hydroxynaphthalene levels that are about 2 to 3 times higher than nonsmokers in both occupationally exposed and general populations (Campo et al., 2006; Nan et al., 2001; Serdar et al., 2003*a*, 2003*b*). Depending on the intensity of exposure, workers exposed to naphthalene have been found to have geometric mean urinary 1- and

Urinary 1-Hydroxynaphthalene (1-Naphthol)

Metabolite of Naphthalene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
T	03-04	**2680** (2360-3050)	**2260** (1980-2650)	**7660** (6270-9420)	**18500** (15500-20900)	**26100** (23000-33600)	2595
A							
6	03-04	**1540** (1360-1750)	**1330** (1110-1680)	**2790** (2180-3520)	**5770** (4110-8200)	**10500** (5870-17000)	340
1	03-04	**1960** (1680-2280)	**1670** (1500-1970)	**4190** (3100-5400)	**10500** (8430-14300)	**20900** (13500-26100)	727
2	03-04	**3020** (2580-3520)	**2650** (2200-3200)	**9420** (7320-11500)	**20500** (16500-23400)	**29400** (23400-37400)	1528
G							
M	03-04	**3170** (2820-3560)	**2840** (2370-3390)	**8790** (7130-11000)	**19600** (16100-22200)	**25800** (22500-30600)	1243
F	03-04	**2290** (1940-2720)	**1840** (1500-2310)	**6380** (4450-8810)	**17900** (14000-21500)	**28500** (21500-37400)	1352
R							
M	03-04	**1950** (1720-2190)	**1650** (1370-2040)	**4380** (3520-5300)	**11600** (9040-15500)	**20100** (14900-22500)	651
N	03-04	**3340** (2800-3990)	**2650** (2190-3460)	**7840** (6520-10800)	**20800** (17000-28600)	**34700** (25400-48900)	695
N	03-04	**2800** (2410-3250)	**2310** (1930-2840)	**8630** (6820-11000)	**19900** (15900-22600)	**27600** (23400-35100)	1084

L

2-hydroxynaphthalene levels that range from around 2 to 100 times higher than the levels in this *Report* (Bieniek 1997; Elovaara et al., 2006; Nan et al., 2001; Serdar et al., 2003*a*).

Finding a measurable amount of 1- or 2-hydroxynaphthalene in the urine does not mean that the level causes an adverse health effect. Biomonitoring studies on levels of 1- and 2-naphthalene provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of naphthalene than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 1-Hydroxynaphthalene (1-Naphthol) (creatinine corrected)

Metabolite of Naphthalene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**2520** (2280-2790)	**2100** (1870-2400)	**6560** (5430-8180)	**15100** (13500-17400)	**21800** (18200-25400)	2595
Age group							
6-11 years	03-04	**1630** (1430-1860)	**1360** (1180-1740)	**2770** (2260-3200)	**5690** (3990-8950)	**10200** (5690-16400)	340
12-19 years	03-04	**1470** (1260-1710)	**1200** (1020-1390)	**2840** (2490-4080)	**7560** (5470-9120)	**10800** (9120-13400)	727
20 years and older	03-04	**2900** (2590-3250)	**2520** (2120-3060)	**8210** (6450-9810)	**16900** (14400-19800)	**24200** (20000-27200)	1528
Gender							
Males	03-04	**2490** (2250-2750)	**2140** (1860-2590)	**6560** (5500-8010)	**13500** (12300-14400)	**18300** (16600-20700)	1243
Females	03-04	**2560** (2220-2950)	**2040** (1730-2440)	**6680** (5000-8850)	**17500** (13500-21700)	**24700** (19800-30600)	1352
Race/ethnicity							
Mexican Americans	03-04	**1750** (1590-1930)	**1500** (1260-1690)	**3240** (2900-4250)	**8550** (7150-12000)	**17500** (13500-21400)	651
Non-Hispanic blacks	03-04	**2370** (2020-2780)	**2000** (1560-2420)	**5900** (4440-7070)	**13800** (8930-18700)	**21100** (17100-27800)	695
Non-Hispanic whites	03-04	**2770** (2460-3120)	**2350** (1940-2900)	**8030** (6330-9260)	**16600** (14400-18500)	**23600** (20000-26600)	1084

Urinary 2-Hydroxynaphthalene (2-Naphthol)

Metabolite of Naphthalene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2470** (2110-2890)	**2280** (1930-2670)	**5680** (4580-6830)	**14700** (12800-19500)	**26000** (22500-29700)	2748
	03-04	**3180** (2760-3670)	**2960** (2500-3500)	**7500** (6190-9690)	**17300** (14500-22100)	**25800** (22600-27700)	2575
Age group							
6-11 years	01-02	**1690** (1560-1840)	**1700** (1400-1950)	**3010** (2580-3470)	**5410** (3890-6700)	**7720** (6300-9540)	387
	03-04	**2110** (1800-2470)	**2140** (1790-2590)	**3570** (3140-4380)	**5580** (5050-6380)	**9710** (5230-20000)	339
12-19 years	01-02	**2220** (1700-2900)	**2150** (1740-2530)	**4390** (3150-6110)	**11000** (6990-20400)	**22500** (13900-28400)	735
	03-04	**3040** (2680-3460)	**2910** (2510-3500)	**5290** (4670-6590)	**12400** (8530-16800)	**17600** (15100-25900)	721
20 years and older	01-02	**2620** (2220-3100)	**2440** (1940-2950)	**6380** (5110-8110)	**17600** (14000-21100)	**28100** (23300-33700)	1626
	03-04	**3360** (2860-3960)	**3180** (2590-3960)	**8770** (7210-11300)	**19200** (16000-23200)	**26600** (23400-28800)	1515
Gender							
Males	01-02	**2750** (2360-3210)	**2510** (2090-2970)	**6060** (4820-7810)	**16900** (11900-23000)	**28100** (20800-35600)	1349
	03-04	**3520** (3090-4010)	**3370** (2910-3880)	**8520** (6960-10500)	**18400** (15300-22600)	**26100** (22200-27900)	1233
Females	01-02	**2220** (1860-2660)	**2060** (1650-2480)	**5240** (3890-6440)	**13900** (12300-17700)	**25300** (19700-28300)	1399
	03-04	**2890** (2420-3450)	**2600** (2140-3160)	**6800** (5140-9210)	**16600** (12700-21300)	**23900** (22100-27600)	1342
Race/ethnicity							
Mexican Americans	01-02	**2700** (2360-3080)	**2710** (2350-3260)	**5140** (4360-6150)	**9640** (8150-10600)	**14300** (10400-18700)	665
	03-04	**3130** (2710-3630)	**3110** (2570-3850)	**6740** (5600-8280)	**14500** (10400-15600)	**18000** (15500-20500)	648
Non-Hispanic blacks	01-02	**3970** (3470-4540)	**3460** (3100-4020)	**9290** (6820-13200)	**22800** (16000-29100)	**33000** (25900-38700)	692
	03-04	**4690** (3830-5750)	**4290** (3250-5540)	**10300** (7670-13100)	**21200** (17300-26100)	**30100** (22300-40600)	690
Non-Hispanic whites	01-02	**2190** (1760-2720)	**1910** (1610-2420)	**4970** (3710-6780)	**14100** (10700-20200)	**25900** (20700-30000)	1207
	03-04	**3080** (2580-3670)	**2660** (2200-3530)	**7640** (5890-10400)	**18000** (14600-22900)	**26100** (22900-27900)	1072

Limit of detection (LOD, see data analysis section) for Survey periods 01-02 and 03-04 are 2.4 and 31.1.

Urinary 2-Hydroxynaphthalene (2-Naphthol) (creatinine corrected)

Metabolite of Naphthalene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**2310** (1980-2680)	**1940** (1670-2300)	**4730** (3820-5860)	**11500** (9980-13100)	**16700** (14100-19200)	2748
	03-04	**2990** (2670-3340)	**2560** (2200-2970)	**6340** (5010-7870)	**14100** (11800-16300)	**19900** (16000-23800)	2575
Age group							
6-11 years	01-02	**1890** (1740-2070)	**1830** (1720-1940)	**3110** (2510-3470)	**5040** (4380-5540)	**6490** (5270-12400)	387
	03-04	**2240** (1890-2650)	**2040** (1660-2440)	**3540** (2840-3910)	**5950** (4140-8510)	**8720** (7560-12000)	339
12-19 years	01-02	**1720** (1350-2190)	**1510** (1340-1830)	**2750** (2080-4070)	**7180** (4070-10900)	**11100** (7860-17400)	735
	03-04	**2280** (2060-2520)	**2030** (1770-2350)	**3780** (3200-4470)	**7840** (6130-9110)	**10500** (9100-12500)	721
20 years and older	01-02	**2480** (2130-2880)	**2080** (1680-2600)	**5630** (4460-6940)	**12400** (10900-13900)	**17700** (15200-20600)	1626
	03-04	**3230** (2870-3640)	**2910** (2360-3410)	**7540** (6200-9100)	**15600** (13100-17900)	**21800** (17200-24000)	1515
Gender							
Males	01-02	**2230** (1900-2610)	**1860** (1630-2100)	**4790** (3510-6120)	**11400** (8950-14300)	**15800** (13100-19200)	1349
	03-04	**2770** (2500-3060)	**2360** (2130-2810)	**6300** (5080-7360)	**12800** (11300-14600)	**16400** (14600-18300)	1233
Females	01-02	**2380** (2050-2770)	**1990** (1660-2560)	**4730** (3790-6000)	**11500** (10300-12800)	**17400** (13700-21500)	1399
	03-04	**3210** (2760-3730)	**2680** (2200-3260)	**6430** (4740-8580)	**16000** (11500-19900)	**22500** (18100-25000)	1342
Race/ethnicity							
Mexican Americans	01-02	**2520** (2230-2850)	**2350** (2010-2950)	**4650** (3970-5210)	**7320** (6050-8090)	**12000** (7820-15300)	665
	03-04	**2830** (2440-3280)	**2570** (2200-3230)	**5000** (4100-5940)	**10300** (6790-13000)	**13300** (11000-15500)	648
Non-Hispanic blacks	01-02	**2790** (2390-3270)	**2410** (2040-2770)	**5980** (4840-6980)	**11600** (9090-15300)	**17400** (12200-23400)	692
	03-04	**3320** (2700-4090)	**3060** (2310-3860)	**7050** (5140-9410)	**12800** (10200-16500)	**19000** (15700-23400)	690
Non-Hispanic whites	01-02	**2160** (1780-2620)	**1740** (1440-2180)	**4340** (3320-6090)	**11900** (9930-14300)	**16900** (13800-20600)	1207
	03-04	**3040** (2660-3460)	**2480** (2110-3020)	**7170** (5100-8950)	**15500** (13300-17600)	**21800** (17100-24000)	1072

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Phenanthrene

CAS No. 85-01-8

Phenanthrene is used in manufacturing dyestuffs and explosives and in biological research. Sources of phenanthrene include diesel fuel exhaust, coal tar pitch and tobacco smoke. Phenanthrene has been found in particle emissions from natural gas combustion and municipal incinerator waste, and in the particulates present in ambient air pollution near high vehicular traffic and industrial or urban areas (ATSDR, 1995; Fang et al., 2006; Rehwagen et al., 2005). IARC determined that phenanthrene was not classifiable with respect to human carcinogenicity.

Biomonitoring Information

Urinary levels of 1-hydroxyphenanthrene, 2-hydroxyphenanthrene, 3-hydroxyphenanthrene, and 4-hydroxyphenanthrene reflect recent exposure. Geometric mean and median urine concentrations of 1- and 3-hydroxyphenanthrene in a 1998 sample of German adults were about 2-fold higher than levels in the NHANES 2001-2002 and 2003-2004 subsamples (Becker et al., 2003). Children and adults in housing where coal tar flooring glue was applied had similar urinary 1-, 2-, 3-, and 4-hydroxyphenanthrene levels compared to residents in houses without the glue; mean levels of these metabolites were higher than levels for similar age groups in this *Report* (Heudorf and Angerer, 2001*a*). Smoking increases levels of urinary 2-, 3-, and 4-hydroxyphenanthrene (Becker et al., 2003; Elovaara et al., 2006; Heudorf and Angerer 2001*b*; Jacob et al., 1999). Occupational PAH exposures have been associated with median urinary phenanthrene metabolite concentrations that range from 10 to 100 times higher than median values in the general population (Elovaara et al., 2006; Gundel et al., 2000).

Finding a measurable amount of one or more urinary phenanthrene metabolites does not mean that the level causes an adverse health effect. Biomonitoring studies on levels of phenanthrene metabolites provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of phenanthrene than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 1-Hydroxyphenanthrene

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**140** (125-158)	**141** (130-154)	**266** (229-312)	**476** (426-539)	**684** (581-763)	2741
	03-04	**156** (140-173)	**166** (150-179)	**287** (263-321)	**464** (423-508)	**625** (538-745)	2496
Age group							
6-11 years	01-02	**119** (104-137)	**121** (98.0-142)	**228** (182-249)	**357** (265-501)	**501** (367-661)	387
	03-04	**138** (124-154)	**131** (111-161)	**222** (200-275)	**397** (304-500)	**615** (384-916)	328
12-19 years	01-02	**133** (110-162)	**131** (110-153)	**238** (198-303)	**431** (376-546)	**579** (439-820)	733
	03-04	**158** (141-178)	**171** (138-193)	**300** (262-333)	**470** (437-537)	**654** (563-745)	692
20 years and older	01-02	**145** (127-164)	**145** (133-164)	**274** (237-329)	**499** (440-565)	**713** (595-819)	1621
	03-04	**157** (141-176)	**167** (152-182)	**296** (264-337)	**469** (430-513)	**625** (534-783)	1476
Gender							
Males	01-02	**150** (133-169)	**145** (132-164)	**284** (235-348)	**501** (424-593)	**713** (575-845)	1344
	03-04	**176** (161-194)	**182** (167-198)	**321** (283-363)	**492** (459-536)	**662** (541-929)	1196
Females	01-02	**132** (115-152)	**137** (121-151)	**254** (221-297)	**464** (390-520)	**654** (538-769)	1397
	03-04	**138** (122-156)	**144** (126-164)	**263** (240-294)	**430** (404-469)	**589** (489-680)	1300
Race/ethnicity							
Mexican Americans	01-02	**117** (90.8-152)	**116** (88.0-147)	**214** (157-306)	**369** (254-583)	**549** (342-847)	664
	03-04	**138** (120-158)	**152** (129-175)	**246** (213-291)	**413** (311-492)	**518** (352-896)	611
Non-Hispanic blacks	01-02	**150** (127-179)	**145** (126-170)	**287** (243-327)	**493** (423-629)	**713** (568-975)	690
	03-04	**182** (152-217)	**178** (149-212)	**346** (274-418)	**552** (459-645)	**797** (606-1050)	679
Non-Hispanic whites	01-02	**144** (125-166)	**144** (131-162)	**276** (241-330)	**489** (436-552)	**661** (550-793)	1204
	03-04	**159** (140-180)	**168** (151-186)	**296** (265-330)	**475** (421-539)	**641** (528-843)	1046

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 3.5 and 5.0.

Urinary 1-Hydroxyphenanthrene (creatinine corrected)

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**132** (118-147)	**125** (113-141)	**210** (191-231)	**344** (310-385)	**464** (404-539)	2741
	03-04	**146** (138-155)	**141** (133-150)	**222** (205-244)	**352** (330-384)	**487** (416-546)	2496
Age group							
6-11 years	01-02	**133** (116-153)	**126** (110-147)	**188** (165-225)	**344** (245-437)	**467** (364-598)	387
	03-04	**145** (129-163)	**138** (121-155)	**205** (169-240)	**315** (244-456)	**477** (313-803)	328
12-19 years	01-02	**103** (87.9-121)	**97.3** (81.4-117)	**158** (131-192)	**240** (198-322)	**354** (235-531)	733
	03-04	**119** (108-130)	**115** (101-131)	**176** (157-197)	**275** (230-331)	**345** (269-496)	692
20 years and older	01-02	**137** (122-153)	**132** (117-145)	**223** (200-243)	**351** (319-395)	**476** (421-541)	1621
	03-04	**151** (142-161)	**147** (134-157)	**237** (212-254)	**365** (335-397)	**500** (422-580)	1476
Gender							
Males	01-02	**122** (108-137)	**116** (104-131)	**194** (173-218)	**321** (262-395)	**455** (348-642)	1344
	03-04	**138** (131-146)	**130** (117-143)	**201** (187-227)	**335** (301-391)	**437** (392-550)	1196
Females	01-02	**142** (125-160)	**136** (118-156)	**226** (199-256)	**355** (323-399)	**473** (421-541)	1397
	03-04	**154** (142-168)	**150** (138-160)	**241** (212-269)	**364** (323-425)	**505** (418-635)	1300
Race/ethnicity							
Mexican Americans	01-02	**110** (88.6-136)	**101** (85.5-131)	**162** (138-203)	**275** (187-452)	**400** (268-755)	664
	03-04	**124** (111-140)	**122** (107-136)	**183** (159-242)	**304** (246-392)	**392** (318-437)	611
Non-Hispanic blacks	01-02	**106** (88.7-127)	**102** (92.4-111)	**172** (141-203)	**274** (224-356)	**384** (308-598)	690
	03-04	**129** (112-148)	**126** (108-143)	**199** (173-242)	**337** (272-400)	**428** (374-522)	679
Non-Hispanic whites	01-02	**142** (126-161)	**137** (119-153)	**228** (206-247)	**363** (321-406)	**476** (411-552)	1204
	03-04	**157** (146-168)	**150** (140-159)	**241** (216-256)	**372** (335-424)	**515** (426-658)	1046

Urinary 2-Hydroxyphenanthrene

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**54.0** (46.0-63.5)	**58.0** (50.0-68.0)	**117** (102-140)	**240** (201-271)	**332** (299-377)	2742
	03-04	**59.3** (52.5-66.9)	**62.2** (55.4-69.7)	**117** (105-129)	**206** (180-235)	**291** (252-336)	2512
Age group							
6-11 years	01-02	**40.5** (34.3-47.7)	**46.0** (37.0-57.0)	**87.0** (71.0-101)	**170** (133-207)	**257** (195-320)	387
	03-04	**45.3** (40.0-51.3)	**48.1** (41.9-56.8)	**72.7** (63.2-89.4)	**135** (104-176)	**225** (136-299)	337
12-19 years	01-02	**49.5** (37.3-65.7)	**52.0** (41.0-68.0)	**108** (93.0-122)	**210** (145-270)	**281** (214-524)	733
	03-04	**58.0** (50.7-66.2)	**62.5** (54.5-71.6)	**104** (88.8-132)	**198** (166-215)	**258** (199-318)	707
20 years and older	01-02	**56.8** (48.1-66.9)	**60.0** (52.0-73.0)	**126** (104-152)	**249** (207-292)	**342** (308-398)	1622
	03-04	**61.5** (53.7-70.4)	**64.9** (57.2-73.5)	**125** (111-138)	**216** (187-250)	**310** (259-389)	1468
Gender							
Males	01-02	**62.1** (53.3-72.5)	**67.0** (58.0-80.0)	**136** (109-161)	**274** (245-303)	**367** (329-414)	1345
	03-04	**72.3** (64.4-81.3)	**71.6** (65.8-83.3)	**138** (123-150)	**240** (200-279)	**337** (279-428)	1211
Females	01-02	**47.4** (39.1-57.5)	**50.0** (41.0-60.0)	**105** (88.0-129)	**200** (171-240)	**294** (236-357)	1397
	03-04	**49.0** (42.4-56.6)	**52.5** (45.3-58.7)	**95.4** (84.1-110)	**166** (146-202)	**247** (202-291)	1301
Race/ethnicity							
Mexican Americans	01-02	**46.8** (32.7-66.8)	**51.0** (36.0-73.0)	**97.0** (72.0-140)	**191** (122-332)	**303** (187-652)	665
	03-04	**53.9** (46.7-62.1)	**60.1** (50.8-68.6)	**104** (89.5-115)	**164** (144-187)	**200** (187-219)	627
Non-Hispanic blacks	01-02	**71.1** (58.0-87.1)	**74.0** (66.0-90.0)	**152** (124-182)	**262** (217-311)	**374** (284-560)	690
	03-04	**81.2** (68.1-96.7)	**73.4** (61.8-101)	**158** (125-199)	**280** (219-374)	**390** (289-574)	678
Non-Hispanic whites	01-02	**53.1** (43.6-64.6)	**57.0** (48.0-68.0)	**117** (99.0-144)	**242** (199-286)	**333** (303-385)	1204
	03-04	**58.2** (50.1-67.7)	**60.7** (52.5-71.0)	**115** (97.9-133)	**209** (172-255)	**299** (251-351)	1044

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 3.2 and 5.0.

Urinary 2-Hydroxyphenanthrene (creatinine corrected)

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**50.6** (43.3-59.2)	**52.5** (46.4-59.6)	**91.4** (78.7-108)	**164** (138-200)	**233** (206-275)	2742
	03-04	**55.4** (51.1-60.0)	**52.3** (48.8-55.8)	**85.8** (79.4-97.0)	**150** (128-174)	**212** (180-252)	2512
Age group							
6-11 years	01-02	**45.3** (38.8-52.8)	**50.0** (40.0-57.8)	**85.9** (69.6-100)	**144** (105-217)	**234** (138-397)	387
	03-04	**47.9** (43.6-52.7)	**46.6** (41.0-51.4)	**66.3** (60.3-72.8)	**106** (81.0-125)	**183** (108-295)	337
12-19 years	01-02	**38.4** (29.6-49.7)	**38.5** (30.6-48.7)	**64.9** (52.4-84.0)	**117** (86.7-167)	**173** (128-305)	733
	03-04	**43.6** (39.3-48.5)	**40.8** (37.7-45.0)	**70.6** (55.8-84.7)	**106** (88.2-123)	**127** (115-176)	707
20 years and older	01-02	**53.7** (46.2-62.4)	**55.6** (49.4-62.7)	**94.6** (84.1-112)	**173** (145-201)	**241** (209-287)	1622
	03-04	**58.7** (53.6-64.2)	**54.8** (50.7-60.9)	**91.6** (83.5-105)	**164** (139-182)	**227** (183-291)	1468
Gender							
Males	01-02	**50.4** (43.3-58.5)	**52.5** (47.2-59.2)	**91.4** (78.6-103)	**176** (140-208)	**245** (206-349)	1345
	03-04	**56.6** (52.5-61.0)	**52.3** (48.1-57.1)	**84.7** (79.2-96.4)	**157** (132-180)	**227** (184-284)	1211
Females	01-02	**50.9** (42.7-60.7)	**52.8** (45.5-61.0)	**91.6** (75.0-115)	**158** (133-183)	**214** (200-245)	1397
	03-04	**54.3** (48.7-60.5)	**52.3** (47.0-57.2)	**88.1** (76.4-101)	**146** (118-179)	**202** (175-246)	1301
Race/ethnicity							
Mexican Americans	01-02	**43.7** (31.9-59.8)	**44.0** (34.3-58.8)	**80.8** (59.8-115)	**146** (103-245)	**245** (144-394)	665
	03-04	**48.8** (42.5-55.9)	**50.1** (42.4-58.8)	**79.5** (68.2-86.1)	**124** (96.2-149)	**155** (127-206)	627
Non-Hispanic blacks	01-02	**50.2** (40.5-62.2)	**49.7** (44.3-56.0)	**87.7** (72.6-103)	**174** (127-224)	**257** (178-459)	690
	03-04	**57.6** (49.8-66.7)	**53.1** (45.7-63.5)	**90.3** (77.9-117)	**152** (128-186)	**218** (173-348)	678
Non-Hispanic whites	01-02	**52.5** (43.8-62.9)	**54.8** (47.7-61.9)	**92.7** (80.5-113)	**170** (140-204)	**233** (202-293)	1204
	03-04	**57.1** (51.7-63.0)	**52.9** (49.1-57.2)	**88.5** (79.2-102)	**159** (128-187)	**237** (180-295)	1044

Urinary 3-Hydroxyphenanthrene

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**105** (92.5-118)	**105** (92.0-118)	**200** (179-225)	**401** (336-480)	**649** (542-747)	2741
	03-04	**115** (104-128)	**118** (107-129)	**219** (201-237)	**424** (351-487)	**647** (509-788)	2426
Age group							
6-11 years	01-02	**105** (91.1-122)	**109** (82.0-138)	**195** (160-231)	**298** (245-346)	**412** (319-545)	387
	03-04	**116** (99.9-134)	**107** (93.0-135)	**205** (170-223)	**333** (241-435)	**472** (322-881)	325
12-19 years	01-02	**104** (87.3-125)	**107** (90.0-122)	**201** (165-231)	**329** (255-445)	**459** (331-631)	733
	03-04	**120** (103-141)	**127** (107-149)	**221** (195-262)	**366** (327-424)	**564** (391-730)	677
20 years and older	01-02	**105** (91.7-119)	**105** (89.0-118)	**201** (180-231)	**433** (366-515)	**683** (597-806)	1621
	03-04	**114** (103-128)	**118** (105-130)	**221** (203-243)	**450** (353-505)	**696** (511-885)	1424
Gender							
Males	01-02	**122** (107-138)	**117** (106-132)	**224** (188-278)	**474** (372-597)	**734** (597-1010)	1344
	03-04	**137** (122-154)	**135** (119-157)	**251** (221-287)	**487** (398-579)	**754** (606-913)	1167
Females	01-02	**90.8** (77.7-106)	**93.0** (80.0-108)	**184** (155-207)	**328** (291-399)	**518** (434-649)	1397
	03-04	**97.7** (86.5-110)	**100** (86.6-114)	**193** (170-210)	**351** (287-445)	**531** (447-647)	1259
Race/ethnicity							
Mexican Americans	01-02	**83.5** (64.1-109)	**84.0** (64.0-111)	**144** (117-198)	**259** (193-430)	**454** (253-1140)	664
	03-04	**92.7** (81.3-106)	**92.8** (84.1-111)	**164** (133-204)	**317** (236-374)	**436** (338-501)	576
Non-Hispanic blacks	01-02	**145** (122-172)	**135** (120-163)	**281** (228-346)	**516** (414-684)	**957** (609-1410)	690
	03-04	**166** (141-195)	**159** (137-193)	**313** (249-399)	**542** (458-670)	**798** (579-1200)	686
Non-Hispanic whites	01-02	**104** (90.8-120)	**106** (92.0-120)	**199** (177-224)	**401** (331-495)	**649** (518-747)	1204
	03-04	**114** (100-129)	**117** (104-128)	**220** (201-237)	**440** (332-509)	**702** (505-915)	1010

Limit of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 3.6 and 5.0.

Urinary 3-Hydroxyphenanthrene (creatinine corrected)

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**98.0** (87.4-110)	**86.5** (78.8-97.1)	**158** (142-174)	**299** (252-342)	**428** (365-621)	2741
	03-04	**108** (101-115)	**99.5** (91.9-106)	**172** (158-189)	**321** (273-363)	**497** (406-566)	2426
Age group							
6-11 years	01-02	**118** (103-135)	**114** (94.9-131)	**173** (150-201)	**289** (238-368)	**410** (308-544)	387
	03-04	**124** (110-138)	**119** (110-129)	**165** (145-202)	**283** (231-402)	**484** (269-710)	325
12-19 years	01-02	**81.1** (70.1-93.8)	**78.0** (66.7-89.4)	**116** (96.5-144)	**205** (153-275)	**283** (198-511)	733
	03-04	**90.3** (81.5-100)	**84.9** (76.1-93.9)	**139** (116-160)	**212** (193-231)	**295** (225-429)	677
20 years and older	01-02	**98.9** (88.3-111)	**85.3** (78.3-96.6)	**164** (147-183)	**320** (273-356)	**488** (379-774)	1621
	03-04	**109** (102-117)	**99.1** (91.7-106)	**180** (161-198)	**343** (282-385)	**523** (417-608)	1424
Gender							
Males	01-02	**98.6** (87.7-111)	**87.1** (79.5-98.2)	**159** (138-188)	**310** (245-368)	**505** (356-761)	1344
	03-04	**107** (98.2-116)	**99.2** (87.4-109)	**169** (154-184)	**305** (261-343)	**491** (383-592)	1167
Females	01-02	**97.5** (84.9-112)	**86.4** (76.9-100)	**158** (139-178)	**292** (245-333)	**410** (352-583)	1397
	03-04	**109** (99.6-119)	**100** (88.9-110)	**176** (155-202)	**328** (265-398)	**497** (380-594)	1259
Race/ethnicity							
Mexican Americans	01-02	**78.2** (62.4-98.0)	**70.8** (56.2-87.4)	**130** (92.9-171)	**224** (173-321)	**333** (224-656)	664
	03-04	**83.8** (75.1-93.6)	**79.5** (72.9-87.0)	**137** (111-165)	**224** (188-274)	**305** (247-406)	576
Non-Hispanic blacks	01-02	**102** (85.8-122)	**91.9** (79.8-108)	**160** (133-202)	**296** (234-475)	**673** (347-1260)	690
	03-04	**118** (103-135)	**106** (90.5-126)	**186** (156-219)	**357** (257-439)	**505** (384-772)	686
Non-Hispanic whites	01-02	**103** (91.5-117)	**89.4** (80.2-102)	**167** (148-193)	**324** (272-368)	**447** (365-738)	1204
	03-04	**112** (104-121)	**103** (96.9-108)	**183** (160-200)	**346** (278-402)	**544** (417-656)	1010

Urinary 4-Hydroxyphenanthrene

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**25.1** (22.6-27.9)	**25.9** (22.5-29.6)	**53.7** (47.4-59.7)	**96.8** (85.0-116)	**152** (118-176)	2443
Age group							
6-11 years	03-04	**25.2** (22.3-28.4)	**26.3** (22.8-30.0)	**45.7** (38.6-53.3)	**95.5** (61.7-137)	**138** (95.1-202)	321
12-19 years	03-04	**23.7** (20.3-27.6)	**25.8** (20.5-31.4)	**49.9** (45.2-53.0)	**77.4** (67.2-95.1)	**123** (94.6-142)	683
20 years and older	03-04	**25.3** (22.4-28.6)	**25.8** (22.4-29.5)	**54.8** (48.6-61.9)	**101** (87.1-120)	**163** (117-197)	1439
Gender							
Males	03-04	**30.0** (26.5-34.0)	**29.6** (25.5-35.1)	**60.4** (53.4-68.7)	**110** (90.6-130)	**169** (118-211)	1180
Females	03-04	**21.1** (18.7-23.8)	**21.3** (18.3-25.3)	**46.5** (41.6-53.3)	**88.4** (73.5-103)	**136** (106-157)	1263
Race/ethnicity							
Mexican Americans	03-04	**23.5** (20.9-26.3)	**24.4** (21.4-29.4)	**46.1** (40.1-53.0)	**80.5** (60.9-94.1)	**99.7** (80.2-154)	607
Non-Hispanic blacks	03-04	**35.4** (29.6-42.3)	**37.1** (29.8-46.1)	**71.4** (60.3-83.3)	**123** (104-145)	**167** (133-215)	657
Non-Hispanic whites	03-04	**24.4** (21.5-27.7)	**25.2** (21.8-29.1)	**51.5** (45.1-58.5)	**97.9** (77.4-127)	**163** (113-202)	1021

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 5.0.

Urinary 4-Hydroxyphenanthrene (creatinine corrected)

Metabolite of Phenanthrene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**23.3** (21.7-25.0)	**22.7** (20.5-24.9)	**42.0** (38.6-44.6)	**74.3** (66.3-85.4)	**114** (102-130)	2443
Age group							
6-11 years	03-04	**26.3** (23.7-29.2)	**24.8** (21.6-28.6)	**43.3** (35.2-48.8)	**72.9** (56.3-113)	**126** (79.3-173)	321
12-19 years	03-04	**17.7** (15.9-19.8)	**16.7** (15.7-18.4)	**31.4** (26.0-37.1)	**47.9** (40.7-54.1)	**61.7** (51.7-86.0)	683
20 years and older	03-04	**24.0** (22.0-26.2)	**23.3** (21.1-25.4)	**43.5** (39.4-48.1)	**79.0** (66.8-100)	**121** (104-138)	1439
Gender							
Males	03-04	**23.4** (21.6-25.4)	**22.7** (20.3-24.9)	**40.9** (35.9-45.7)	**72.7** (61.5-86.8)	**112** (100-126)	1180
Females	03-04	**23.2** (21.2-25.5)	**22.8** (19.7-26.0)	**42.5** (38.3-46.2)	**75.1** (63.4-94.0)	**119** (93.1-139)	1263
Race/ethnicity							
Mexican Americans	03-04	**21.2** (18.8-23.8)	**20.7** (19.1-22.9)	**35.9** (29.8-40.7)	**59.0** (43.3-87.5)	**83.4** (60.9-139)	607
Non-Hispanic blacks	03-04	**25.0** (21.6-28.9)	**25.3** (23.1-28.8)	**42.0** (37.4-51.4)	**75.0** (61.6-87.9)	**102** (79.2-137)	657
Non-Hispanic whites	03-04	**23.7** (21.5-26.2)	**22.4** (19.4-25.4)	**43.6** (38.8-47.3)	**82.2** (68.5-101)	**126** (103-143)	1021

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Jacob J, Grimmer G, Dettbarn G. Profile of urinary phenanthrene metabolites in smokers and non-smokers. Biomarkers 1999;4(5):319-327.

Pyrene

CAS No. 129-00-0

Pyrene has been used as a starting material for producing optical brighteners and dyes. Notable pyrene sources include domestic heating sources, particularly wood burning; gasoline fuel exhaust; coal tar and asphalt; and cigarette smoke. Pyrene is commonly found in PAH mixtures, and its urinary metabolite, 1-hydroxypyrene, has been used widely as an indicator of exposure to PAH chemicals, particularly in occupational exposure studies. IARC determined that pyrene was not classifiable as to its human carcinogenicity.

Biomonitoring Information

Urinary levels of 1-hydroxypyrene reflect recent exposure. The overall geometric mean of 1-hydroxypyrene levels in the NHANES 2003-2004 subsample was similar to that of general populations in other industrialized countries (Becker et al., 2003; Chuang et al., 1999; Goen et al., 1995; Heudorf and Angerer 2001*a*, 2001*b*; Yang et al., 2003). Higher levels have been noted in residents of industrialized and high traffic urban areas compared with rural or suburban settings, and the mean urinary 1-hydroxypyrene levels from the former group were somewhat higher than in the NHANES 2003-2004 subsample (Kanoh et al., 1993; Kuo et al., 2004; Yang et al., 2003). Variation also has been noted in the mean 1-hydroxypyrene urine levels between different industrialized countries (for example, South Korea or China, compared to the U.S.), which is attributable to such factors as ambient air pollution and residential heating and cooking sources (Huang et al., 2004; Kuo et al., 2004; Roggi et al., 1997; Siwinska et al., 1999; Yang et al., 2003). In general, smokers have about 2 to 4-fold higher urinary 1-hydroxypyrene levels than non-smokers (Goen et al., 1995; Heudorf and Angerer 2001*b*; Jacob et al., 1999). Environmental tobacco smoke may contribute to higher urinary 1-hydroxypyrene levels in exposed children (Chuang et al., 1999; Siwinska et al., 1999; Tsai et al., 2003).

Numerous studies of workers with occupational exposure to excessive vehicular exhaust have found increased urinary 1-hydroxypyrene levels compared to non-exposed individuals (Kuusimaki et al., 2004; Merlo et al., 1998; Tsai et al., 2004). The highest urinary levels of 1-hydroxypyrene measured in occupational studies have been found in aluminum smelter and coke oven workers exposed to heated tar and coal tar products (Alexandrie et al., 2000; Goen et al., 1995; Jacob and Seidel, 2002; Lu et al., 2002; Serdar et al., 2003). Results in these workers have ranged from about 100 to more than 1000 times greater than non-exposed levels and the geometric mean values found in this *Report*. Tobacco smoking also was associated with levels about double those in nonsmoking workers (Campo et al., 2006; Merlo et al., 1998; Mukherjee et al., 2004).

Finding a measurable amount of urinary 1-hydroxypyrene does not mean that the level of 1-hydroxypyrene causes an adverse health effect. Biomonitoring studies on levels of 1-hydroxypyrene provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of pyrene than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Urinary 1-Hydroxypyrene

Metabolite of Pyrene

Geometric mean and selected percentiles of urine concentrations (in ng/L) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**89.2** (79.8-99.7)	**91.3** (83.5-98.8)	**189** (168-208)	**389** (345-459)	**569** (493-676)	2515
Age group							
6-11 years	03-04	**112** (96.9-130)	**119** (99.0-143)	**193** (163-229)	**351** (233-484)	**514** (336-680)	333
12-19 years	03-04	**119** (103-137)	**115** (98.0-145)	**244** (213-274)	**506** (359-608)	**705** (636-788)	705
20 years and older	03-04	**82.8** (73.0-93.8)	**83.8** (75.6-92.4)	**177** (155-203)	**387** (337-437)	**553** (483-644)	1477
Gender							
Males	03-04	**108** (96.0-122)	**111** (98.7-121)	**227** (197-265)	**459** (387-518)	**644** (526-811)	1214
Females	03-04	**74.0** (64.3-85.1)	**75.3** (66.3-83.9)	**158** (143-173)	**334** (258-407)	**502** (389-604)	1301
Race/ethnicity							
Mexican Americans	03-04	**89.4** (78.6-102)	**92.4** (79.8-113)	**173** (153-191)	**331** (281-415)	**495** (404-548)	623
Non-Hispanic blacks	03-04	**128** (105-155)	**126** (108-153)	**296** (226-355)	**553** (400-669)	**699** (564-935)	681
Non-Hispanic whites	03-04	**84.8** (73.5-97.9)	**85.4** (75.6-97.3)	**182** (156-214)	**386** (336-462)	**566** (470-749)	1050

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 5.0.

Urinary 1-Hydroxypyrene (creatinine corrected)

Metabolite of Pyrene

Geometric mean and selected percentiles of urine concentrations (in ng/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	**83.4** (77.4-90.0)	**79.9** (72.6-86.9)	**149** (133-167)	**279** (236-343)	**424** (352-474)	2515
Age group							
6-11 years	03-04	**119** (102-138)	**112** (98.2-137)	**185** (156-225)	**336** (227-440)	**475** (336-566)	333
12-19 years	03-04	**89.4** (77.7-103)	**81.6** (74.3-93.0)	**146** (123-187)	**269** (196-364)	**364** (251-611)	705
20 years and older	03-04	**79.1** (73.2-85.4)	**73.5** (66.7-82.3)	**142** (127-160)	**278** (236-331)	**424** (349-472)	1477
Gender							
Males	03-04	**84.8** (77.3-93.1)	**82.8** (72.7-91.0)	**163** (145-175)	**290** (241-352)	**416** (353-513)	1214
Females	03-04	**82.1** (73.5-91.7)	**78.3** (69.2-86.8)	**137** (119-165)	**274** (215-350)	**440** (313-479)	1301
Race/ethnicity							
Mexican Americans	03-04	**81.2** (73.9-89.2)	**80.9** (70.4-91.7)	**146** (122-167)	**247** (221-301)	**372** (321-460)	623
Non-Hispanic blacks	03-04	**91.0** (77.7-107)	**92.4** (76.6-106)	**173** (145-211)	**315** (227-433)	**451** (301-680)	681
Non-Hispanic whites	03-04	**83.3** (75.4-92.0)	**77.9** (69.1-86.8)	**148** (127-174)	**287** (241-360)	**438** (360-506)	1050

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Benzene

CAS No. 71-43-2

General Information

Benzene is a volatile chemical that is produced commercially from coal and petroleum sources. It is among the most abundantly produced chemicals in the U.S. and is used extensively as an industrial solvent, in the synthesis of numerous chemicals, and as an additive in unleaded gasoline (ATSDR, 2007).

Human exposure occurs primarily by inhaling benzene in ambient air (Hattemer-Frey et al., 1990; Wallace, 1996). Sources of benzene in the air may result from either natural (e.g., forest fires) or industrial sources. Among industrial sources, automobile emissions and vapor around gasoline filling stations contribute to benzene in air (ATSDR, 2007). Tobacco smoke contributes to benzene in indoor air (Duarte-Davidson, et al., 2001), and tobacco smoke is estimated to account for about half of the total estimated exposure to benzene (ATSDR, 2007). Indoor sources for benzene, which include the offgassing of building materials, account for a significant portion of a non-smoker's benzene exposure (Wallace, 1996; Wallace et al., 1987). The consumption of food, drinking water, and beverages are considered negligible sources of exposure unless benzene contamination has occurred, such as from leaking underground fuel storage tanks (ATSDR, 2007; Wallace, 1996). In recent years, less than five percent of domestic wells used for drinking water in the U.S. have been found to contain detectable amounts of benzene (Rowe et al., 2007). Workplace exposure to benzene may result from production, use, or transportation of petroleum products.

Benzene is well absorbed after inhalational, oral, or dermal exposure. In the blood, benzene is distributed rapidly throughout the body, especially into the brain and fatty tissues, and can cross the placenta. Benzene is metabolized in the liver, and some metabolites may be distributed to the bone marrow, where additional metabolism may result in toxic effects on hematopoietic cells (ATSDR, 2007; Ross, 2000). The primary benzene metabolites are phenol, catechol, hydroquinone, 1,2,4-benzenetriol, and to a lesser extent, *trans*, *trans*-muconic acid, which are eliminated in urine as glucuronide and sulfate conjugates (Ross, 2000). Urinary S-phenylmercapturic and *t,t*-muconic acids are used for monitoring workplace exposure. A very small amount of unchanged benzene is eliminated in the breath.

Blood Benzene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**.030** (<LOD-.050)	**.100** (.060-.140)	**.190** (.140-.290)	**.320** (.190-.480)	837
	03-04	*	**.027** (.025-.031)	**.064** (.050-.084)	**.170** (.150-.190)	**.260** (.210-.320)	1345
Age group							
20-59 years	01-02	*	**.030** (<LOD-.050)	**.100** (.060-.140)	**.190** (.140-.290)	**.320** (.190-.480)	837
	03-04	*	**.027** (.025-.031)	**.064** (.050-.084)	**.170** (.150-.190)	**.260** (.210-.320)	1345
Gender							
Males	01-02	*	**.030** (<LOD-.050)	**.110** (.060-.160)	**.230** (.150-.370)	**.370** (.210-.510)	403
	03-04	**.039** (.035-.043)	**.030** (.027-.035)	**.069** (.053-.084)	**.160** (.140-.180)	**.240** (.190-.320)	654
Females	01-02	*	**.030** (<LOD-.050)	**.100** (.060-.130)	**.180** (.120-.240)	**.250** (.170-.330)	434
	03-04	*	**.025** (<LOD-.029)	**.057** (.040-.090)	**.180** (.150-.220)	**.290** (.220-.420)	691
Race/ethnicity							
Mexican Americans	01-02	*	**.030** (<LOD-.070)	**.070** (.030-.170)	**.140** (.060-.360)	**.230** (.130-.370)	227
	03-04	*	**.027** (<LOD-.035)	**.041** (.034-.057)	**.077** (.058-.110)	**.130** (.084-.320)	254
Non-Hispanic blacks	01-02	*	**< LOD**	**.060** (<LOD-.160)	**.180** (.090-.300)	**.250** (.160-.480)	137
	03-04	**.043** (.033-.058)	**.029** (<LOD-.054)	**.092** (.055-.140)	**.210** (.140-.290)	**.320** (.240-.460)	302
Non-Hispanic whites	01-02	*	**.030** (<LOD-.060)	**.110** (.070-.160)	**.210** (.140-.340)	**.330** (.190-.510)	411
	03-04	*	**.028** (.025-.033)	**.068** (.053-.088)	**.180** (.150-.200)	**.280** (.210-.330)	687

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.024 and 0.024.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Accidental and intentional exposures to high concentrations of benzene vapor can lead rapidly to euphoria, central nervous system depression, cardiac arrhythmias, followed by unconsciousness and death (ATSDR, 2007). Workers have developed skin irritation following repeated dermal exposure and mucous membrane irritation following repeated vapor inhalation (ATSDR, 2007). Epidemiologic studies of workers in industries involving benzene have found that benzene exposure can cause bone marrow suppression and increases the risk of various leukemias (Savitz and Andrews, 1997). Supportive evidence for benzene carcinogenicity comes from animal studies and from *in vitro* studies demonstrating the clastogenic properties of benzene on blood forming cells (NTP, 1986; Ross, 2000). The background exposure levels for the general population have been estimated to be much lower than the estimated lowest effect level for benzene at which leukemia risk is increased (Duarte-Davidson, et al., 2001).

Workplace standards and guidelines for benzene have been established by OSHA and ACGIH, respectively. The U.S. EPA has established environmental and drinking water standards for benzene, and the FDA has established a bottled water standard. Benzene is classified as a known human carcinogen by IARC and by NTP. Information about external exposure (ie., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of blood benzene reflect recent exposure. The median level of blood benzene observed in the NHANES 2003-2004 subsample appear slightly lower than the median level in a nonrepresentative subsample of adults in NHANES III (1988-1994) (Ashley et al., 1994), as well for other previous studies of the U.S. general population (Bonanno et al., 2001; Buckley et al., 1997; Sexton et al., 2005 and 2006; Lin et al., 2008), and studies from other countries (Brugnone et al., 1994; Navasumrit et al., 2005).

Smoking, residing, or working in urban areas and exposure to gasoline and petroleum products can result in blood benzene levels that are higher than those in the nonsmoking general population (Ashley et al., 1995; Carrer et al., 2000; Backer et al., 1997). The amount and duration of cigarette smoking increases the likelihood of higher blood benzene levels (Bonanno et al., 2001; Churchill et al., 2001; Lin et al., 2008). Workers exposed to gasoline fumes, such as garage mechanics, drivers, and street vendors, and workers exposed to solvent fumes have been found to have blood benzene levels as much as tenfold higher than levels in the general population (Brugnone, et al., 1994 and 1999; Moolenaar et al., 1997; Perbellini et al., 2002; Romieu et al., 1999).

Finding a measurable amount of benzene in blood does not mean that the level of benzene causes an adverse health effect. Biomonitoring studies of blood benzene can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of benzene than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Chlorobenzenes

Chlorobenzene (Monochlorobenzene)
CAS No. 108-90-7

1,2-Dichlorobenzene (*o*-dichlorobenzene)
CAS No. 95-50-1

1,3-Dichlorobenzene (*m*-dichlorobenzene)
CAS No. 541-73-1

1,4-Dichlorobenzene (*p*-dichlorobenzene, Paradichlorobenzene) CAS No. 106-46-7

General Information

Chlorobenzene (monochlorobenzene) and the three dichlorobenzenes are halogenated aromatic hydrocarbons pirmarily used in industrial and chemical synthetic processes. Chlorobenzene has been used to produce DDT, phenol, and nitrobenzene. The dichlorobenzenes are also chemical intermediates in synthesis of dyes, pesticides, and other industrial products. The chlorobenzenes have sometimes been used as solvents for pesticides and auto parts degreasers (ATSDR, 2007). 1,4-Dichlorobenzene (1,4-DCB; para-dichlorobenzene) is used also as a moth repellent and as a deodorizer (ATSDR, 2007).

Ambient air is the primary source of chlorobenzene exposure for the general population. Indoor air levels of 1,4-DCB may exceed outdoor levels when moth repellents or deodorizers are in use (Wallace et al., 1987, 1991). Dietary sources are negligible (Schaum et al., 2003), and chlorobenzenes generally are not detected in drinking water or groundwater in the United States (USGS, 2006), but may be detected where industrial waste containing these chemicals has been discharged (IPCS, 2004). Chlorobenzenes volatilize from soil and water (ATSDR, 2007, 2008). People involved in the production or use of chlorobenzenes may be exposed by inhalation or dermal contact. Chlorobenzenes are well absorbed after inhalation and ingestion. 1,4-DCB is not appreciably absorbed through intact skin. Within a few hours following exposure, these chemicals are eliminated from tissues via oxidative hepatic metabolism followed by conjugation or oxidation. The major urinary metabolites are dichlorophenols (ATSDR, 2007, 2006).

Human health effects from chlorobenzenes at low environmental doses or at biomonitored levels from low environmental exposures are unknown. In humans, high air levels of 1,2- or 1,4-dichlorobenzenes cause eye and nasal irritation, and prolonged or repeated contact with concentrated solutions of either chemical may cause skin irritation or sensitization (Elovaara, 1998). Asthma and reduced pulmonary function have been associated with recent exposure to aromatic chemicals, including 1,4-DCB, but causation is unclear (Arif and Shah, 2007; Elliott et al., 2006). Laboratory animals exposed to high levels of chlorobenzene may demonstrate liver enlargement and serum transaminase elevations, renal tubular cell damage, and central nervous system depression. High doses of 1,2- or 1,3-dichlorbenzenes can result in centrilobular liver necrosis and decreased thyroid hormone levels and, among

Blood Chlorobenzene (Monochlorobenzene)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1366
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1366
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	669
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	694

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.011.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

male animals, renal tubular degeneration (ATSDR, 2007; Elovaara, 1998; NTP, 1987). 1,4-DCB is not as acutely hepatotoxic or thyrotoxic as the other dichlorobenzene isomers (den Besten et al., 1991, 1992; Stine et al., 1991). In animal studies, 1,4-DCB is not considered to be a reproductive or developmental toxicant (ATSDR, 2007, 2008; Elovaara, 1998). Animals fed high doses of 1,4-DCB demonstrated an increased incidence of renal and hepatic tumors, but no evidence was found of mutagenicity or genotoxicity *in vitro* (NTP, 1987).

The U.S. EPA and the FDA regulate the levels of 1,2- or 1,4-dichlorobenzene in air and water and in bottled drinking water, respectively. U.S. EPA regulates the monochlorobenzene level in drinking water. NIOSH and ACGIH provide workplace guidelines for 1,2- and 1,4-dichlorobenzenes and monochlorobenzene levels in air. IARC classified 1,4-dichlorobenze as a possible human carcinogen and NTP determined that it was reasonably anticipated to be a human carcinogen. However, IARC determined that the human carcinogenicity of 1,2-dichlorobenzene and 1,3-dichlorobenzene was unclassifiable. Additional information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of chlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, and 1,4-dichlorobenzene in blood reflect recent exposure. Data from the NHANES 2003-2004 subsample are shown in the tables for all the chlorobenzenes. In addition, the table for 1,4-dichlorobenzene shows data from the NHANES 2001-2002 subsample.

Generally, blood levels of chlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene were not detected in NHANES 2003-2004 and were detected in only less than 10% of the U.S. general population samples in earlier surveys (Ashley et al., 1994; Elliott et al., 2006). For 1,4-dichlorobenzene, a nonrepresentative sample of adults from the National Health and Nutrition Examination Survey (NHANES) III (1988–1994) demonstrated a median level of 1,4-DCB level of 0.33 µg/L (Hill et al., 1995), or equivalent to the 75th percentile of the NHANES 2003-2004 subsample, and about three times higher than levels found in a sample of Midwestern adults and children (Bonanno et al., 2001). A small study of urban, low-income children monitored over a two year period reported that median 1,4-DCB blood levels were slightly lower than NHANES III (Sexton et al., 2005, 2006). Ambient air and blood levels have been shown to correlate reasonably well (Lin et al., 2008; Sexton et al., 2005). Residential construction and cleaning activities, including the recent use of toilet bowl deodorants, may contribute to elevated indoor air and blood levels of 1,4-DCB (Bonanno et al., 2001; Churchill et al., 2001).

Finding a measurable amount of chlorobenzenes in the urine does not mean that the level of chlorobenzene causes an adverse health effect. Biomonitoring studies of urinary chlorobenzenes can provide physicians and public health officials with reference values so that they can determine

Blood 1,2-Dichlorobenzene (*o*-Dichlorobenzene)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1327
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1327
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	647
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	680
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	250
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	291
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	682

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.1.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

whether people have been exposed to higher levels of chlorobenzenes than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Blood 1,3-Dichlorobenzene (*m*-Dichlorobenzene)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1334
Age group							
20-59 years	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1334
Gender							
Males	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	659
Females	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	675
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	266
Non-Hispanic blacks	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	279
Non-Hispanic whites	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	686

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.05.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood 1,4-Dichlorobenzene (Paradichlorobenzene)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**.300** (.190-.550)	**1.19** (.610-2.90)	**4.10** (1.40-7.60)	807
	03-04	*	**< LOD**	**.320** (.250-.400)	**1.10** (.710-1.60)	**3.30** (1.70-5.10)	1322
Age group							
20-59 years	01-02	*	**< LOD**	**.300** (.190-.550)	**1.19** (.610-2.90)	**4.10** (1.40-7.60)	807
	03-04	*	**< LOD**	**.320** (.250-.400)	**1.10** (.710-1.60)	**3.30** (1.70-5.10)	1322
Gender							
Males	01-02	*	**< LOD**	**.270** (.180-.530)	**.900** (.570-2.90)	**3.60** (1.10-7.20)	390
	03-04	*	**< LOD**	**.320** (.250-.380)	**.770** (.580-1.20)	**1.90** (1.20-4.00)	651
Females	01-02	*	**< LOD**	**.360** (.190-.620)	**1.20** (.620-3.90)	**4.10** (1.68-8.30)	417
	03-04	*	**< LOD**	**.350** (.220-.450)	**1.40** (.810-2.10)	**4.10** (2.20-5.90)	671
Race/ethnicity							
Mexican Americans	01-02	**.331** (.246-.446)	**.180** (<LOD-.260)	**.790** (.400-1.30)	**6.00** (1.30-16.0)	**16.0** (6.20-33.0)	217
	03-04	**.381** (.256-.566)	**.210** (.140-.400)	**.730** (.370-2.90)	**6.20** (2.90-9.30)	**10.0** (6.30-19.0)	262
Non-Hispanic blacks	01-02	**.558** (.376-.827)	**.360** (.260-.560)	**1.80** (.710-3.90)	**6.30** (1.40-29.0)	**15.0** (3.60-51.0)	136
	03-04	**.423** (.292-.613)	**.340** (.200-.480)	**.980** (.550-1.50)	**4.10** (1.60-9.20)	**11.0** (2.50-19.0)	297
Non-Hispanic whites	01-02	*	**< LOD**	**.200** (<LOD-.380)	**.570** (.300-1.20)	**1.19** (.570-3.70)	396
	03-04	*	**< LOD**	**.200** (.160-.260)	**.490** (.370-.720)	**.940** (.690-2.00)	658

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.12 and 0.12.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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1,2-Dibromo-3-Chloropropane (DBCP)

CAS No. 96-12-8

General Information

1,2-Dibromo-3-chloropropane (DBCP) is a liquid soil fumigant used until 1985 when the U.S. Environmental Protection Agency (U.S. EPA) banned applications (ATSDR, 1992). DBCP volatilizes from soil into the air after application. Recent surveys of U.S. public drinking water supplies have not detected DBCP (USGS, 2006).

Exposure to the general population is rare. In the past, inhalational and dermal exposure occurred primarily in formulators and applicators. DBCP can be absorbed by ingestion, inhalation, and dermal routes. After absorption, DBCP is shown in animal studies to distribute widely into most tissues. Metabolites are excreted in urine, feces, and, to a limited extent, exhaled air (ATSDR, 1992; MacFarland et al., 1984).

In animal studies, large acute doses of DBCP produce lethargy, ataxia, and convulsions. High chronic doses in laboratory animals demonstrate kidney toxicity, testicular injury and reduced sperm production, and altered estrus cycles and infertility (ATSDR, 1992; Lag et al., 1989; Rao et al., 1982). Male workers exposed during DBCP production have demonstrated oligospermia or azoospermia; sperm count recovery occurred generally with less than 3 years of workplace exposure (Potashnik, 1983; Potashnik and Yani-Inbar, 1987; Whorton et al., 1979; Lipschultz et al., 1980). In general populations, epidemiologic investigations found no association between exposure to previously contaminated drinking water and birth rates, birth outcomes, gastric cancer, or leukemia (Whorton et al., 1989; Wong et al., 1988).

An increased risk for certain cancers was found in several studies of workers exposed to DBCP (Olsen et al., 1995; Wesseling et al., 1996); however, these studies may have been confounded by other unmeasured exposures. Rodents that were administered DBCP developed tumors in the nasal cavity, lungs, and forestomach (NCI, 1978; NTP, 1982). The International Agency for Research on Cancer classified DBCP as a possible human carcinogen; the National Toxicology Program determined that DBCP was reasonably anticipated to be a human carcinogen. U.S. EPA established drinking water and other environmental standards and the Occupational Safety and Health Administration established workplace standards for DBCP. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of DBCP in blood reflect recent exposure. In the general population, DBCP was not detected in the NHANES 2003-2004 subsample, similar to other studies (Ashley et al. 1994; Churchill et al., 2001). Finding a measurable amount of DBCP in the blood does not mean that the level of DBCP causes an adverse health effect. Biomonitoring studies of DBCP in the blood can provide physicians and

Blood 1,2-Dibromo-3-chloropropane (DBCP)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1170
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1170
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	568
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	602
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	234
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	239
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	603

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.1.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

public health officials with reference values so that they can determine whether people have been exposed to higher levels of DBCP than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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2,5-Dimethylfuran

CAS No. 625-86-5

General Information

2,5-Dimethylfuran is a volatile chemical found in tobacco smoke (Baggett et al., 1974) and in roasted coffee aroma (Wang et al., 1983). Exposure among the general population may occur through inhaling cigarette smoke and coffee aroma. 2,5-Dimethylfuran in blood and exhaled air has been used to determine smoking status (Ashley et al., 1996; Gordon et al., 2002; Perbellini et al., 2003). In addition, levels of 2,5-dimethylfuran found in blood provide a rough estimate of the number of cigarettes smoked per day (Ashley et al., 1995, 1996). After a person smokes cigarettes, 2,5-dimethylfuran is absorbed from the respiratory tract and then rapidly eliminated from the blood (Egle and Gochberg, 1979; Gordon et al., 2002). 2,5-Dimethylfuran is also a human urinary metabolite of *n*-hexane. Workers exposed to *n*-hexane will eliminate 2,5-dimethylfuran, along with other metabolites, in their urine (ATSDR, 2007; Iwata et al., 1983; Mutti et al., 1984; Perbellini et al., 1981).

Human health effects from 2,5-dimethylfuran at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Neither IARC or NTP has evaluated 2,5-dimethylfuran's human carcinogenicity. 2,5-Dimethylfuran is not mutagenic by *in vitro* testing (Zeiger et al., 1992).

Biomonitoring Information

Levels of 2,5-dimethylfuran in blood reflect recent exposure and are generally undetectable among nonsmoking adults and in the general population. Ashley et al. (1995) and Perbellini et al. (2003) reported median blood 2,5-dimethylfuran levels of 0.13 µg/L in smokers which were similar values to the 95th percentile in participants of NHANES 2003-2004 reflecting the U.S. population mix of nonsmokers and smokers. Levels of 2,5-dimethylfuran in blood increase generally with the number of cigarettes smoked per day (Ashley et al., 1995, 1996).

Finding a measurable amount of 2,5-dimethylfuran in blood does not mean that the level of 2,5-dimethylfuran causes an adverse health effect. Biomonitoring studies of 2,5-dimethylfuran in blood can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of 2,5-dimethylfuran than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Blood 2,5-Dimethylfuran

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**< LOD**	**.015** (<LOD-.031)	**.100** (.083-.110)	**.140** (.120-.180)	1221
Age group							
20-59 years	03-04	*	**< LOD**	**.015** (<LOD-.031)	**.100** (.083-.110)	**.140** (.120-.180)	1221
Gender							
Males	03-04	*	**< LOD**	**.019** (<LOD-.031)	**.094** (.071-.110)	**.130** (.110-.190)	602
Females	03-04	*	**< LOD**	**< LOD**	**.110** (.074-.120)	**.150** (.120-.210)	619
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**< LOD**	**.012** (<LOD-.020)	**.038** (.013-.054)	237
Non-Hispanic blacks	03-04	*	**< LOD**	**.041** (.018-.063)	**.110** (.079-.160)	**.170** (.099-.220)	261
Non-Hispanic whites	03-04	*	**< LOD**	**.020** (<LOD-.041)	**.110** (.087-.120)	**.150** (.120-.210)	628

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.012.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Ethylbenzene

CAS No. 100-41-4

General Information

Ethylbenzene is a flammable hydrocarbon found in crude oil. It is a high production chemical used largely to synthesize styrene and also as a solvent and an additive to automobile and aviation fuels. Automobile emission contributes a significant amount of ethylbenzene to outdoor air. Indoor sources of ethylbenzene include carpet adhesives and tobacco smoke. Ethylbenzene is ubiquitous in ambient air, with higher concentrations in areas with greater vehicular traffic. It undergoes biodegradation or photooxidation in air, water, and soil, and it does not bioaccumulate in aquatic food chains (ATSDR, 2007). Producing and using petroleum products are potential sources of workplace exposure to ethylbenzene.

The general population may be exposed to ethylbenzene through inhalation, particularly from motor vehicle emissions, self-service gasoline pump vapors, and cigarette smoke. Drinking water is contaminated rarely by leaking underground storage tanks containing petroleum products. Ethylbenzene is well absorbed by inhalation, oral, or dermal exposure routes. After absorption, ethylbenzene is metabolized rapidly by the liver. Mandelic and phenylglyoxylic acids are the predominant urinary metabolites and have been used to monitor workplace exposure (Knecht et al., 2000).

Human health effects from ethylbenzene at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Ethylbenzene can cause respiratory tract and eye irritation and dizziness at air concentrations that exceed workplace standards (Cometto-Muniz and Cain, 1995). Much higher levels occurring with accidental exposures can produce central nervous system depression. Laboratory animals exposed to ethylbenzene for several weeks to months at air concentrations several times higher than occupational standards have shown respiratory irritation, increased liver weight, liver microsomal enzyme induction, and increased leukocyte counts (ATSDR, 2007). Chronic animal exposure studies have also demonstrated renal tubular, alveolar, and hepatic tumors with some evidence of gender-specific susceptibility (NTP, 1999).

The IARC classified ethylbenzene as a possible human carcinogen. OSHA and ACGIH established workplace standards and guidelines, respectively, for ethylbenzene.

Blood Ethylbenzene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**.034** (.029-.039)	**.030** (.030-.040)	**.050** (.050-.070)	**.090** (.070-.120)	**.140** (.090-.180)	879
	03-04	**.035** (.033-.037)	**.032** (.030-.036)	**.053** (.048-.057)	**.083** (.077-.088)	**.110** (.098-.120)	1299
Age group							
20-59 years	01-02	**.034** (.029-.039)	**.030** (.030-.040)	**.050** (.050-.070)	**.090** (.070-.120)	**.140** (.090-.180)	879
	03-04	**.035** (.033-.037)	**.032** (.030-.036)	**.053** (.048-.057)	**.083** (.077-.088)	**.110** (.098-.120)	1299
Gender							
Males	01-02	**.035** (.029-.041)	**.030** (<LOD-.040)	**.060** (.040-.070)	**.100** (.070-.150)	**.150** (.090-.220)	419
	03-04	**.037** (.034-.041)	**.036** (.031-.040)	**.057** (.051-.065)	**.086** (.078-.099)	**.110** (.094-.130)	625
Females	01-02	**.033** (.028-.038)	**.030** (.030-.040)	**.050** (.040-.060)	**.080** (.060-.120)	**.130** (.070-.180)	460
	03-04	**.032** (.030-.034)	**.030** (.027-.033)	**.048** (.041-.053)	**.081** (.071-.089)	**.100** (.091-.120)	674
Race/ethnicity							
Mexican Americans	01-02	*	**.030** (<LOD-.040)	**.040** (.040-.060)	**.070** (.050-.110)	**.120** (.070-.210)	220
	03-04	**.031** (.027-.036)	**.029** (<LOD-.035)	**.044** (.035-.048)	**.064** (.051-.074)	**.091** (.066-.170)	253
Non-Hispanic blacks	01-02	**.032** (.027-.038)	**.030** (<LOD-.040)	**.050** (.030-.070)	**.080** (.060-.130)	**.130** (.070-.240)	159
	03-04	**.032** (.027-.038)	**.030** (<LOD-.037)	**.050** (.037-.066)	**.079** (.065-.100)	**.110** (.084-.130)	281
Non-Hispanic whites	01-02	**.035** (.029-.043)	**.030** (<LOD-.040)	**.060** (.050-.070)	**.090** (.070-.140)	**.150** (.090-.190)	432
	03-04	**.036** (.034-.038)	**.034** (.030-.038)	**.055** (.050-.061)	**.087** (.081-.092)	**.110** (.098-.130)	669

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.024 and 0.024.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.

The U.S. EPA established environmental and drinking water standards for ethylbenzene. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of ethylbenzene in blood reflect recent exposure. In a nonrepresentative subsample of adults in the National Health and Nutrition Examination Survey (NHANES) III (1988-1994), the median ethylbenzene level in blood was 0.060 µg/L (Ashley et al., 1994), which is similar to the geometric mean value reported for nonsmokers in the NHANES 1999-2000 subsample (Lin et al., 2008). The geometric mean level in participants 20 years and older in the NHANES 2001-2002 and 2003-2004 subsamples appear similar or slightly below these previously reported values, though differences in methodology and sampled populations may account for slight differences in levels. Also, approximately similar levels were observed in sample of southwestern U.S. residents (Buckley et al., 1997), but such levels were about two to three times higher than levels reported among low-income children in a Midwestern U.S. city (Sexton et al., 2005, 2006).

Smoking cigarettes increases blood ethylbenzene levels, but environmental tobacco smoke exposure appears not to increase blood ethylbenzene (Lin et al., 2008; Perbellini et al., 2002). Residents in high density urban areas and commuters may have ethylbenzene levels up to two times higher than the nonsmoking general population (Lemire et al., 2004). Street vendors and workers exposed to gasoline fumes can have blood ethylbenzene levels up to ten times higher than levels found in the general population (Mannino et al., 1995; Romieu et al., 1999). Workers in the petroleum industry and those with solvent exposure can have blood ethylbenzene levels that are several hundred times higher than those in the general population (Angerer and Wulf, 1985; Kawai et al., 1992).

Finding a measurable amount of ethylbenzene in the blood does not mean that the level of ethylbenzene causes an adverse health effect. Biomonitoring studies of ethylbenzene in blood can provide physicians and public health officials with reference values so that they can determine whether people have been exposed to higher levels of ethylbenzene than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Halogenated Solvents

Dichloromethane (Methylene chloride)
CAS No. 75-09-2

Trichloroethene (Trichloroethylene) CAS No. 79-01-6

Tetrachloroethene (Tetrachloroethylene, Perchloroethylene) CAS No. 127-18-4

General Information

Dichloromethane, trichloroethene, and tetrachloroethene are volatile halogenated short-chain hydrocarbons. Dichloromethane is used principally as a solvent in paint removers and thinners, as well as in other household products (cleaners, glues, and adhesives), and also as a degreasing agent. Trichloroethene is used primarily as an industrial degreaser, solvent, and in the synthesis of other chemicals. In the past, it was used in dry cleaning, food processing, household cleaners, and as a general anesthetic. Tetrachloroethene is used in dry cleaning, metal cleaning, the synthesis of other chemicals, and household products such as water repellants, silicone lubricants, and spot removers. All three of these halogenated solvents are produced and used in high volumes in the U.S., and have been detected in urban and ambient air and occasionally, soils, and drinking water most likely contaminated by industrial discharge (Moran et al., 2007; Rowe et al., 2007). Because of their volatility, these solvents do not persist in the soil or water following the discontinuation of contamination.

Inhalation is the most common exposure route for the general population including indoor sources from paints, adhesives, and cleaning solutions. Volatilization from contaminated water (eg., shower water) as well as the use of household products containing these solvents can result in higher indoor than outdoor air concentrations (ATSDR, 1997*b*; Martin et al., 2005). Nearby dry cleaning establishments, industries producing these solvents, and contaminated waste disposal sites can also contribute to human exposure (Armstrong and Green, 2004; ATSDR, 1997*a*, 1997*b*, and 2000; Schreiber et al., 1993; Wallace et al., 1991). Drinking water may contribute to exposure when underground drinking water supplies have been contaminated. Workers in industries such as dry cleaning, aircraft maintenance, electronics manufacturing, and chemical production may be exposed by inhalation or by dermal contact with the liquid solvents. The U.S. EPA has established drinking water standards and other environmental standards for all three solvents, and the FDA regulates tetrachloroethene and trichloroethene as indirect food additives. For all three solvents, workplace standards have been established by OSHA, and ACGIH has recommended occupational guidelines and biological exposure indices for monitoring workers.

All three solvents are well absorbed by ingestion and inhalation, and animal studies have demonstrated that liquid forms can be dermally absorbed. Following absorption, part of the solvent dose is excreted into expired air; for tetrachloroethene, about 97-99% of the dose is eliminated unmetabolized into expired air, though it has an elimination half-life of several days (ATSDR1997*a*; Monster et

Blood Dichloromethane (Methylene chloride)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1165
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1165
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	568
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	597
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	225
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	245
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	607

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.07.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

al., 1986). The retained solvent can undergo hepatic metabolism. Trichloroethene and tetrachloroethene are metabolized to trichloroacetic acid and tricholoroethanol, which are eliminated in the urine. Dichloromethane is partially metabolized to carbon monoxide and carbon dioxide. Elevated carboxyhemoglobin levels in blood have been reported following intentional dichloromethane overdose or exposure to air concentrations greatly exceeding occupational standards (ATSDR, 2000; Hughes and Tracy, 1993).

Human health effects from dichloromethane, tetrachloroethene, and trichloroethene at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Accidental or intentional high dose acute exposure by ingestion or inhalation of any of these solvents can result in loss of motor coordination, somnolence, and unconsciousness. Inhaling high doses of trichloroethene and tetrachloroethene may also produce cardiac arrhythmias attributed to enhanced sensitivity to catecholamines. High dose acute exposure to tetrachloroethene has resulted in reversible kidney impairment, and prolonged, low level exposure to either tetrachloroethene or trichloroethene has been associated with altered renal enzyme excretion and liver enlargement (ATSDR, 1997*a*, *b*). Chronic occupational exposure to any of these three solvents may be associated with mild degrees of neurological impairments, including reaction times, verbal skills, cognitive ability and motor function (Armstrong and Green, 2004).

Various epidemiologic studies of chronic tetrachloroethene exposure in dry cleaning workers found increased incidences of esophageal and cervical cancers and non-Hodgkins lymphoma, but confounding exposures (e.g., other solvents and trichloroethene) were likely (IPCS, 2006). In animals studies, tetrachloroethene and trichloroethene each induced kidney and liver tumors; tetrachloroethene also caused leukemia, and trichloroethene caused lung and testicular tumors (IARC, 1995). Animal studies of inhaled dichloromethane have reported increased incidences of lung and hepatocellular cancers, and in female animals, mammary gland tumors (NTP, 2004). Trichloroethene and tetrachloroethene are classified as probable human carcinogens by IARC, and dichloromethane is classified as a possible human carcinogen by IARC. All three are classified as reasonably anticipated to be human carcinogens by NTP. Additional information about these solvents is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Blood Trichloroethene (Trichloroethylene)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	< LOD	< LOD	< LOD	922
	03-04	*	< LOD	< LOD	< LOD	< LOD	1228
Age group							
20-59 years	01-02	*	< LOD	< LOD	< LOD	< LOD	922
	03-04	*	< LOD	< LOD	< LOD	< LOD	1228
Gender							
Males	01-02	*	< LOD	< LOD	< LOD	< LOD	434
	03-04	*	< LOD	< LOD	< LOD	< LOD	604
Females	01-02	*	< LOD	< LOD	< LOD	< LOD	488
	03-04	*	< LOD	< LOD	< LOD	< LOD	624
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	< LOD	< LOD	< LOD	228
	03-04	*	< LOD	< LOD	< LOD	< LOD	224
Non-Hispanic blacks	01-02	*	< LOD	< LOD	< LOD	< LOD	191
	03-04	*	< LOD	< LOD	< LOD	< LOD	266
Non-Hispanic whites	01-02	*	< LOD	< LOD	< LOD	< LOD	441
	03-04	*	< LOD	< LOD	< LOD	< LOD	644

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.012 and 0.012.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

Levels of halogenated solvents in blood reflect recent exposure. In the NHANES 2003-2004 subsample, the level of blood tetrachloroethene for adults at the 75th percentile of the U.S. population appear similar to the levels at the 75th percentile reported for non-smoking adults in a subsample of NHANES 1999-2000 participants (Lin et al., 2008) and were similar or slightly less that levels reported in a nonrepresentative subsample of the earlier NHANES III (1988-1994) (Ashley et al., 1994; Churchill et al., 2001). A recent study of low income, urban children in the Midwest reported slightly lower median tetrachloroethene levels (Sexton et al., 2005; Sexton et al., 2006) than the NHANES III levels (Ashley et al., 1994; Churchill et al., 2001). Other population studies have reported similarly low tetrachloroethene levels (Begerow et al., 1996; Bonanno et al., 2001). Population studies in Italy and Germany have reported multifold higher tetrachloroethene and trichloroethene blood levels than the U.S. surveys (Brugnone et al., 1994; Hajimiragha et al., 1986). Blood levels of trichloroethene and dichloromethane were detected infrequently in previous U.S. surveys and were generally not detected in the NHANES 2003-2004 subsample.

Comparatively higher blood levels of tetrachloroethene and trichloroethene have been noted for urban and industrial residential settings than for rural settings (Barkley et al., 1980; Begerow et al., 1996; Brugnone et al., 1994). Residing near dry-cleaning facilities or storing recently dry-cleaned clothes at home can contribute to increased blood tetrachloroethene levels (Begerow et al., 1996; Popp et al., 1992). In contrast, tetrachloroethene blood levels in occupationally exposed workers have been reported to be many thousand times higher than the unexposed general population (Begerow et al., 1996; Furuki et al., 2000; Monster et al., 1983). The occupational biological exposure index associated with an 8-hour exposure of 25 ppm is 500 µg/L tetrachloroethene in blood (ACGIH, 2007). Non-occupational exposures are usually well below this level.

Finding a measurable amount of any of these solvents in blood does not mean that the level of the solvent causes an adverse health effect. Biomonitoring studies of blood halogenated solvents can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of halogenated solvents than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Blood Tetrachloroethene (Perchloroethylene)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**.050** (<LOD-.060)	**.100** (.070-.150)	**.190** (.130-.260)	978
	03-04	*	**< LOD**	**< LOD**	**.076** (.060-.097)	**.140** (.091-.300)	1317
Age group							
20-59 years	01-02	*	**< LOD**	**.050** (<LOD-.060)	**.100** (.070-.150)	**.190** (.130-.260)	978
	03-04	*	**< LOD**	**< LOD**	**.076** (.060-.097)	**.140** (.091-.300)	1317
Gender							
Males	01-02	*	**< LOD**	**.050** (<LOD-.060)	**.110** (.070-.170)	**.210** (.170-.340)	457
	03-04	*	**< LOD**	**< LOD**	**.082** (.060-.140)	**.230** (.097-.410)	639
Females	01-02	*	**< LOD**	**.050** (<LOD-.060)	**.100** (.070-.140)	**.150** (.100-.220)	521
	03-04	*	**< LOD**	**< LOD**	**.069** (.050-.091)	**.120** (.085-.180)	678
Race/ethnicity							
Mexican Americans	01-02	*	**< LOD**	**< LOD**	**.060** (<LOD-.070)	**.070** (.060-.230)	226
	03-04	*	**< LOD**	**< LOD**	**.049** (<LOD-.097)	**.100** (.054-.180)	248
Non-Hispanic blacks	01-02	*	**< LOD**	**< LOD**	**.070** (.050-.110)	**.110** (.060-.190)	195
	03-04	*	**< LOD**	**< LOD**	**.086** (.050-.220)	**.220** (.082-.360)	284
Non-Hispanic whites	01-02	*	**< LOD**	**.050** (<LOD-.070)	**.110** (.090-.170)	**.210** (.150-.260)	487
	03-04	*	**< LOD**	**< LOD**	**.072** (.060-.091)	**.140** (.085-.330)	686

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.048 and 0.048.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Other Halogenated Solvents

Dibromomethane CAS No. 74-95-3

1,1-Dichloroethane
CAS No. 75-34-3

1,2-Dichloroethane (Ethylene dichloride)
CAS No. 107-06-2

1,1-Dichloroethene (Vinylidene chloride)
CAS No. 75-34-3

***cis*-1,2-Dichloroethene** CAS No. 156-59-2

***trans*-1,2-Dichloroethene** CAS No. 156-60-5

1,2-Dichloropropane CAS No. 78-87-5

1,1,1-Trichloroethane (Methyl chloroform)
CAS No. 71-55-6

1,1,2-Trichloroethane CAS No. 79-00-5

1,1,2,2-Tetrachloroethane CAS No. 79-34-5

Tetrachloromethane (Carbon tetrachloride)
CAS No. 56-23-5

General Information

The halogenated solvents are volatile organic chemicals consisting of a hydrocarbon chain or one hydrocarbon substituted with one or more chlorine or bromine atoms. Most of these chemicals are used as degreasers and solvents in various products such as paints. In the past, 1,1,1-trichloroethane was used as a dry cleaning agent, insect fumigant, and solvent in consumer products; more recently, its U.S. production has been restricted because of its principal use in manufacturing hydrofluorocarbons (Armstrong, et al., 2004; ATSDR, 2006*b*). Production of 1,1,2,2-tetrachloroethane in the U.S. has ceased, and currently, it is only used as a chemical intermediate in the production of several other halogenated solvents (ATSDR, 2006*a*). 1,1,2-trichloroethane, 1,2-dichloroethane and 1,1-dichloroethene are used in the synthesis of other chemicals, such as polyvinylidene. Tetrachloromethane use as a solvent and fumigant has been discontinued due to toxicity concerns, and its other major use, production of chlorofluorocarbon refrigerants, has been restricted as a result of regulations of ozone-depleting chemicals (ATSDR, 2005).

These volatile halogenated solvents may be released into the air from facilities that produce or use them, from contaminated waste water, or from hazardous waste sites. In surveys of U.S. drinking water, 1,1,1-trichloroethane was one of the most frequently detected chlorinated solvents; detected in less than 10 percent of domestic wells (Moran et al., 2007; Rowe et al., 2007). When 1,1,1-trichlorethane was available in consumer products, indoor air concentrations

Blood Dibromomethane

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1355
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1355
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	666
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	689
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	292
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	693

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.03.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

could exceed outdoor air concentrations (Wallace, et al., 1991). Because of their volatility, these halogenated solvents generally do not persist in soil or water. Workers involved in the production or use of these solvents may be exposed by inhalation or by dermal contact with the liquid solvents.

Inhalation is the most common exposure route for the general population, including indoor sources from such as paints, adhesives, cleaning solutions, and aerosolized insecticide sprays; from industries producing these solvents; and from contaminated waste disposal sites (Armstrong et al., 2004; ATSDR, 2006*a* and 2001). Drinking water may contribute to exposure due to contaminated underground drinking water supplies. In general, these solvents are well absorbed by inhalation, dermal, or oral exposure. After absorption, small amounts may be exhaled in expired air, and the remaining amount rapidly distributed to tissues. 1,1,1-Trichloroethane is exceptional in that most of a dose is exhaled unchanged in expired air and less than 10 percent of a dose is metabolized (Monster, et al., 1979). Fatty tissues can transiently accumulate these solvents, which are slowly released back into the blood stream. Many of these halogenated solvents are metabolized to more water soluble metabolites that can be excreted in the urine. Hepatic transformation of tetrachloromethane may lead to the generation of reactive intermediate metabolites which may be responsible for liver toxicity (Weber et al., 2003). Other halogenated solvents may undergo similar metabolism to reactive intermediates that contribute to toxicity (Casciola and Ivanetich, 1984; IPCS, 2003; Raucy et al., 1993).

Human health effects from these solvents at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Acute exposure to massive doses by either inhalation or ingestion can cause central nervous system depression and unconsciousness, cardiac dysrhythmias, and hepatic and renal injury. Eye and respiratory tract irritation may occur with exposure to high vapor concentrations of most of these solvents, and allergic contact dermatitis has been reported following 1, 2-dichloroethane dermal exposure (Baruffini et al., 1989). Exposures to vapor concentrations exceeding occupational standards have been associated with fatigue, headache, delayed reactions, and neuropsychological impairment (ATSDR, 2001; Bowler et al., 2003). Epidemiologic studies of workers exposed to various halogenated solvents have found occasional associations between exposure and reduced fertility and spontaneous abortion in women (Figa-Talamanca, 2006). In animal studies, reproductive toxicity has not been consistently demonstrated in the absence of maternal toxicity (IPCS, 1990, 1992, and 1993).

Experimental animals exposed chronically to high doses of each of these solvents developed tumors of the liver, lung, and kidney. In addition, lymphoid and hematopoietic tumors were observed with 1,2-dichloroethane and 1,1,1-trichloroethane; mammary gland tumors were observed with tetrachloromethane, 1,2-dichloroethane, and 1,1-dichloroethene. IARC has determined that the dichloroethanes and tetrachloromethane are possible human carcinogens; the other halogenated solvents in this section are not classifiable regarding human carcinogenicity. NTP has determined that tetrachloromethane and

Blood 1,1-Dichloroethane

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	670
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	695

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.01.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

1,2-dichloroethane are reasonably anticipated to be human carcinogens. With the exception of dibromomethane, the U.S. EPA has established drinking water standards and other environmental criteria. The FDA regulates several of these solvents in bottled water and as indirect food additives. Occupational standards and guidelines are available for most of these chemicals from OSHA and ACGIH, respectively. Further information on the halogenated solvents is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of halogenated solvents in blood reflect recent exposure. Except for tetrachloromethane in the NHANES 2003-2004 subsample, the other ten halogenated solvents were detectable in less that a few percent of the participants. In a non-representative sample of adults in NHANES III (1988-1994), blood levels were also non-detectable or detected in <10% of samples, except for 1,1,1-trichloroethane which was detected in a majority of samples with a median of 0.13 µg/L (Ashley et al., 1994; Churchill et al., 2001). 1,1,1-Trichloroethane was not detected in children who underwent periodic blood testing as part of an environmental exposure study (Sexton et al., 2005 and 2006). In a study of German residents, 1,1,1-trichloroethane levels were of similar magnitude to the NHANES III study (Hajimiragha et al., 1986).

Finding a measurable amount of any of these halogenated solvents in blood does not mean that the level of the solvent causes an adverse health effect. Biomonitoring studies of blood halogenated solvents can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of halogenated solvents than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

Blood 1,2-Dichloroethane (Ethylene dichloride)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1346
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1346
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	661
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	685
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	289
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	689

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.01.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood 1,1-Dichloroethene (Vinylidene chloride)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	670
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	695

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.009.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood *cis*-1,2-Dichloroethene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1366
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1366
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	669
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	694

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.01.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood *trans*-1,2-Dichloroethene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1367
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	670
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	695

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.01.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood 1,2-Dichloropropane

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1364
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1364
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	667
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	692

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.008.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood 1,1,1-Trichloroethane (Methyl chloroform)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1345
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1345
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	660
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	685
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	289
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	688

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.048.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood 1,1,2-Trichloroethane

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1354
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1354
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	664
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	690
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	297
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	686

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.01.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood 1,1,2,2-Tetrachloroethane

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1235
Age group							
20-59 years	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1235
Gender							
Males	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	613
Females	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	622
Race/ethnicity							
Mexican Americans	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	250
Non-Hispanic blacks	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	282
Non-Hispanic whites	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	606

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.01.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Blood Tetrachloromethane (Carbon tetrachloride)

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	**< LOD**	**.010** (<LOD-.010)	**.010** (<LOD-.140)	**.020** (.010-.050)	742
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1362
Age group							
20-59 years	01-02	*	**< LOD**	**.010** (<LOD-.010)	**.010** (<LOD-.140)	**.020** (.010-.050)	742
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	1362
Gender							
Males	01-02	*	**< LOD**	**.010** (<LOD-.010)	**.010** (<LOD-.140)	**.010** (.010-.040)	364
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	667
Females	01-02	*	**< LOD**	**.010** (<LOD-.010)	**.010** (<LOD-.090)	**.040** (.010-.080)	378
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	695
Race/ethnicity							
Mexican Americans	01-02	*	**< LOD**	**< LOD**	**.010** (<LOD-.750)	**.020** (.010-.050)	193
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	266
Non-Hispanic blacks	01-02	*	**< LOD**	**.010** (<LOD-.010)	**.010** (<LOD-.020)	**.010** (<LOD-.020)	132
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	299
Non-Hispanic whites	01-02	*	**< LOD**	**.010** (<LOD-.010)	**.010** (<LOD-.140)	**.030** (.010-.080)	366
	03-04	*	**< LOD**	**< LOD**	**< LOD**	**< LOD**	692

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.01 and 0.005.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Hexachloroethane

CAS No. 67-72-1

General Information

Hexachloroethane is a solid that sublimates at room temperature. It is primarily used in combination with zinc or titanium oxides in military pyrotechnic or smoke generating devices, as an agent to degas or purify molten ores, as an ignition and explosive suppressant, and as a vulcanizing agent. Hexachloroethane is no longer produced in the U. S., and usage has declined since the 1970's (ATSDR, 1997). In the past, hexachloroethane was used as an ingredient in some pesticides, in fire extinguisher fluids, and as a veterinary antihelminthic (ATSDR, 1997). Hexachloroethane can enter the atmosphere from emissions during its production and use, or as a byproduct from the chlorination of other hydrocarbons. Hexachloroethane is relatively persistent in the environment and has been detected a low levels in ambient air and rarely in drinking water systems (USGS, 2006).

For the general population, hexachloroethane exposure is infrequent and occurs by inhaling contaminated air. A less common pathway is the ingestion of contaminated drinking water. Workers in metal and alloy refining or pyrotechnic and smoke device production may be exposed to larger amounts. Hexachloroethane is absorbed by inhalation, dermal and ingestion routes, and it is preferentially distributed to fat, kidney and liver. Metabolism in the liver results in formation of trichloroacetic acid and trichloroethanol, which are excreted in urine (ATSDR, 1997). A small portion of unmetabolized hexachloroethane is excreted in the feces.

Human health effects from hexachloroethane at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Workers exposed to hexachloroethane reported irritation of the skin and mucous membranes, but no changes were noted in pulmonary function tests or in serum tests of renal, pancreatic, and liver function (Selden et al., 1994, Selden et al., 1997). Animals exposed to high air levels of hexachloroethane developed ataxia, facial twitching, tremors, and pneumonitis (Weeks et al., 1979). In feeding studies, animals developed dose-related abnormalities of the liver (enlargement, transaminase elevation, centrilobular necrosis) and kidney (tubular nephrosis and nephrocalcinosis) (ATSDR, 1997). Animal carcinogenicity studies show inconsistent evidence of hepatocellular carcinomas (NCI, 1978), an increased incidence of renal tumors in males (NTP, 1989), and no clear evidence of mutagenicity or genotoxicity. Hexachloroethane does not appear to be a reproductive or developmental toxicant in animal studies (ATSDR, 1997).

Hexachloroethane is classified as a possible human carcinogen by IARC and is reasonably anticipated to be a human carcinogen by NTP. The U.S. EPA has established drinking water and other environmental regulations for hexachloroethane. Workplace standards and guidelines for hexachloroethane have been established by OSHA and ACGIH, respectively. Information about external exposure (ie., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Blood Hexachloroethane

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1366
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1366
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	669
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	697
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	267
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	300
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	694

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.011.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Information

Levels of hexachloroethane in the blood reflect recent exposure. Blood levels were not detectable in the NHANES 2003-2004 subsample as has been the case in several other general population studies (Ashley et al., 1994; Buckley et al., 1997; Foster, 1995; Selden et al., 1993).

Finding a measureable amount of hexachloroethane in blood does not mean that the level of hexachloroethane causes an adverse health effect. Biomonitoring studies of blood hexachloroethane can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of hexachloroethane than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Methyl *tert*-Butyl Ether (MTBE)

CAS No. 1634-04-4

General Information

Methyl *tert*-butyl ether (MTBE) was added to reformulated gasoline to boost octane and to reduce carbon monoxide exhaust emissions in high smog areas of the United States in the1980s. Because of concerns for groundwater contamination and water quality, MTBE was banned or its usage was limited in several states. Ethanol has replaced MTBE as an additive to reformulated gasoline (U.S. DOE, 2003 and 2006; U.S. EPA, 2000). MTBE contamination of groundwater has been more common in urban areas (Squillace et al., 2004) and in areas near leaking underground storage tanks (Rowe et al., 2007). MTBE also has been detected in ambient air near blending facilities, in cities where MTBE is used in reformulated gasoline, and in the breathing zone during consumer refueling at service stations (IPCS, 1998). MBTE is also used in small amounts as a laboratory solvent and as a pharmaceutical agent (ATSDR, 1996).

The general population is exposed to MBTE primarily by inhalation of contaminated air. Contaminated water is a less common source though exposure can occur by ingestion or inhalation of vaporized MTBE from water (IPCS, 1998). Workplace exposure to MTBE may occur in the production, transportation, and use of petrochemicals. MTBE is well absorbed after inhalational, oral, or dermal exposure and is rapidly cleared from the blood with an estimated half-life of several hours (Dekant et al., 2001). Most MTBE absorbed by the body is metabolized by the liver and then eliminated in urine, primarily as 2-hydroxyisobutyrate with *tert*-butyl alcohol and 2-methyl-1,2-propanediol as minor urinary metabolites (Amberg et al., 1999; Amberg et al., 2001). Depending upon the dose, more than one third of inhaled MTBE may be excreted in exhaled air (ATSDR, 1996; Nihlen et al., 1998).

Human health effects from MTBE at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Following the introduction of MTBE reformulated gasoline, complaints of respiratory tract irritation, headache, nausea, and dizziness prompted several population surveys, epidemiologic studies, and experimental human volunteer studies that provided little evidence of an association between MTBE exposure and health complaints (ATSDR, 1996). Based upon high dose animal studies, MTBE has been considered to be a skin and

Blood Methyl *tert*-butyl ether (MTBE)

Geometric mean and selected percentiles of blood concentrations (in pg/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**16.4** (4.77-56.7)	**27.7** (7.29-64.9)	**73.8** (35.5-127)	**132** (64.0-278)	**188** (109-339)	672
	03-04	**11.0** (5.98-20.1)	**10.0** (4.60-25.1)	**45.0** (16.0-98.0)	**110** (70.0-180)	**170** (110-340)	1307
Age group							
20-59 years	01-02	**16.4** (4.77-56.7)	**27.7** (7.29-64.9)	**73.8** (35.5-127)	**132** (64.0-278)	**188** (109-339)	672
	03-04	**11.0** (5.98-20.1)	**10.0** (4.60-25.1)	**45.0** (16.0-98.0)	**110** (70.0-180)	**170** (110-340)	1307
Gender							
Males	01-02	**16.9** (4.96-57.7)	**27.9** (6.82-64.6)	**75.0** (35.5-131)	**132** (54.9-307)	**167** (109-417)	334
	03-04	**12.2** (6.29-23.6)	**11.0** (4.80-29.0)	**55.0** (18.0-110)	**130** (79.0-200)	**200** (110-470)	641
Females	01-02	**16.0** (4.12-61.8)	**26.6** (5.93-74.6)	**72.7** (32.6-132)	**142** (73.5-255)	**194** (92.3-336)	338
	03-04	**9.88** (5.62-17.4)	**8.90** (4.30-23.0)	**38.0** (14.0-85.0)	**94.0** (58.0-160)	**140** (90.0-250)	666
Race/ethnicity							
Mexican Americans	01-02	**23.3** (4.96-110)	**33.4** (2.92-187)	**91.3** (26.1-255)	**225** (80.6-339)	**273** (182-358)	166
	03-04	**11.6** (5.35-25.3)	**12.0** (3.80-29.0)	**32.0** (14.0-80.0)	**80.0** (38.0-190)	**160** (74.0-220)	245
Non-Hispanic blacks	01-02	**14.9** (6.11-36.4)	**26.4** (3.11-55.6)	**52.6** (30.0-86.8)	**87.4** (38.6-155)	**120** (70.0-155)	119
	03-04	**9.63** (4.83-19.2)	**10.0** (3.50-28.0)	**32.8** (11.0-85.0)	**77.0** (36.0-160)	**140** (61.0-210)	285
Non-Hispanic whites	01-02	**16.0** (4.13-62.4)	**27.9** (4.71-74.6)	**72.7** (33.3-132)	**132** (59.6-249)	**165** (92.8-366)	333
	03-04	**11.5** (5.51-23.8)	**11.0** (4.00-33.5)	**59.0** (14.0-120)	**120** (73.0-230)	**180** (110-430)	673

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.232 and 2.0.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.

eye irritant (IPCS, 1998). Animal studies of carcinogenicity have been inconclusive (ATSDR, 1996). MTBE does not appear to be a reproductive or developmental in animal studies (IPCS, 1998). Methyl *tert*-butyl ether is unclassifiable as a human carcinogen by IARC. The U.S. EPA has established standards and guidelines for MTBE in water and air, and ACGIH has adopted guidelines for workplace air exposure. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of MTBE in blood reflect recent exposure. In the NHANES 2003-2004 subsample, MTBE was detectable in most of the population; the geometric mean was 11.0 pg/mL for the total population. In a subsample of adults in NHANES 1999-2000, Lin et al. (2008) found geometric mean blood levels of MTBE to be 17 and 15 pg/mL in smokers and non-smokers, respectively. In a small study of U.S. automobile drivers when MTBE was used as a fuel additive, blood levels were about 100 times higher than those in the NHANES subsamples (White et al., 1995). Commuters in urban areas with high vehicular traffic had median blood MTBE blood levels that were more than tenfold higher than those in the U.S. general population (Lemire et al., 2004). Workers exposed to oxygenated gasoline fumes and vehicle exhaust had levels that were by 10 to 100 times higher than general population levels (Mannino et al., 1995; Moolenaar et al., 1994; Romieu et al., 1999; White et al., 1995), depending in part on the concentration of MTBE in the gasoline.

Finding a measurable amount of MTBE in blood does not mean that the level of MTBE causes an adverse health effect. Biomonitoring studies of blood MTBE can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of MTBE than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Nitrobenzene

CAS No. 98-95-3

General Information

Nitrobenzene is a synthetic aromatic chemical made from benzene and used to manufacture aniline, which is in turn, is used to make some types of polyurethanes. Nitrobenzene is also used in the synthesis of other chemicals, including pesticides, dyes, and explosives and as a solvent in petroleum refining. Less common or discontinued applications include use in shoe polish, special lubricating oils, and as an almond flavoring. Environmental sources for nitrobenzene include emissions from its production or use and the atmospheric chemical reaction of benzene with nitrogen oxides. Nitrobenzene was detected infrequently at low levels in ambient air taken in urban, rural and waste disposal areas in the 1970s and 1980s (IPCS, 2003). Nitrobenzene was rarely detected in surface and industrial effluent water and was not detected in soil and sediment specimens obtained from selected locations in the United States (IPCS, 2003).

The general population can be exposed infrequently to nitrobenzene in contaminated air and water. Workers may be exposed to nitrobenzene during its use or production. Nitrobenzene is absorbed after dermal, inhalational, or oral exposure and then metabolized to various intermediates. About 10 to 20 percent of a dose is eliminated in the urine as *p*-nitrophenol, which is used in biological monitoring of occupational exposures. A smaller fraction of a dose is eliminated in urine as *p*-aminophenol (Astier, 1992; IARC, 1996). The nitroreduced metabolites of nitrobenzene may mediate some toxic effects (e.g., methemoglobinemia or carcinogenicity) (IPCS, 2003).

Human health effects from nitrobenzene at low environmental doses or at biomonitored levels from low environmental exposures are unknown. People having accidental exposures to large amounts of nitrobenzene have developed methemoglobinemia, hemolytic anemia, and toxic hepatitis (IARC, 1996). In animals treated with high doses of nitrobenzene, methemoglobinemia, testicular atrophy and reduced sperm counts, and increased liver and kidney weights were observed (NTP, 2002). In animals exposed to high concentrations of nitrobenzene in air, multiple tumors were observed, depending on gender, including lung, thyroid, mammary gland, liver, and kidney tumors (Cattley et al., 1994; NTP, 2002). Nitrobenzene is classified by IARC as a possible human carcinogen and by NTP as reasonably anticipated to be human carcinogen. The U.S. EPA has established environmental standards for nitrobenzene. Workplace standards and guidelines for nitrobenzene have been established by OSHA and ACGIH, respectively. The ACGIH recommends biological exposure indices to monitor workplace exposure. Information about external exposure (ie., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of nitrobenzene in blood reflect recent exposure. In

Blood Nitrobenzene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	03-04	*	< LOD	< LOD	< LOD	< LOD	1066
Age group							
20-59 years	03-04	*	< LOD	< LOD	< LOD	< LOD	1066
Gender							
Males	03-04	*	< LOD	< LOD	< LOD	< LOD	529
Females	03-04	*	< LOD	< LOD	< LOD	< LOD	537
Race/ethnicity							
Mexican Americans	03-04	*	< LOD	< LOD	< LOD	< LOD	206
Non-Hispanic blacks	03-04	*	< LOD	< LOD	< LOD	< LOD	205
Non-Hispanic whites	03-04	*	< LOD	< LOD	< LOD	< LOD	564

Limit of detection (LOD, see Data Analysis section) for Survey year 03-04 is 0.3.
Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

the NHANES 2003-2004 subsample, nitrobenzene was not detected. Finding a measureable amount of nitrobenzene in blood does not mean that the level of nitrobenzene causes an adverse health effect. Biomonitoring studies of blood nitrobenzene can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of nitrobenzene than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Styrene

CAS No. 100425

General Information

Styrene is a high production, hydrocarbon chemical used to manufacture of polystyrene resins, which are widely used in plastic packaging, disposal cups and containers, insulation, adhesives, and in composite materials such as fiberglass. It is also used to produce synthetic rubber and latex. Because styrene is synthesized largely from ethylbenzene, it may be present in products made from styrene. Styrene is commonly detected in urban air, especially near industrial sites where it is produced and used, and in high motor vehicle traffic areas. Air concentrations of styrene may be greater indoors than outdoors, as a result of emissions from photocopiers and laser printers, cigarette smoke, and consumer products in the home (ATSDR, 2007; Wallace et al., 1987). Styrene does not persist in the aquatic or soil environments because of its volatility and is rarely detected in U.S. groundwater or drinking water supplies (USGS, 2006).

For the general population, inhalation of styrene is the primary exposure route. Trace amounts can be ingested when styrene migrates from packaging into foods. Styrene is well absorbed by inhalation, ingestion or dermal routes. Workplace exposure may occur during the production of styrene or products derived from styrene. After absorption, styrene is metabolized within hours by the liver. The main urinary excretion products are mandelic acid and phenylglyoxylic acid, which have been used in monitoring workplace exposure (ATSDR, 2007; Brugnone et al., 1993; Ramsey et al., 1980). The U.S. EPA has established a drinking water and other environmental standards for styrene. Workplace standards and guidelines for styrene have been established by OSHA and ACGIH, respectively. The ACGIH recommends biological exposure indices to monitor workplace exposure.

Human health effects from styrene at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Eye and upper respiratory tract irritation occur after several hours of exposure to air concentrations that exceed the occupational standard for workers. Several studies of chronic occupational exposure to styrene reported neurological effects, including altered color vision, vestibular dysfunction, impaired hearing and altered performance on neuropsychological and neurophysiological tests (ATSDR, 2007). Various studies of workers with styrene exposure have not provided

Blood Styrene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	.080 (.050-.100)	.130 (.090-.200)	.200 (.140-.260)	950
	03-04	*	< LOD	.050 (.044-.061)	.089 (.081-.097)	.120 (.110-.130)	1245
Age group							
20-59 years	01-02	*	< LOD	.080 (.050-.100)	.130 (.090-.200)	.200 (.140-.260)	950
	03-04	*	< LOD	.050 (.044-.061)	.089 (.081-.097)	.120 (.110-.130)	1245
Gender							
Males	01-02	*	< LOD	.080 (.050-.110)	.140 (.100-.230)	.220 (.140-.340)	445
	03-04	*	< LOD	.056 (.045-.068)	.089 (.081-.100)	.120 (.095-.150)	608
Females	01-02	*	< LOD	.070 (.050-.100)	.120 (.090-.180)	.180 (.120-.260)	505
	03-04	*	< LOD	.048 (.040-.060)	.090 (.074-.100)	.110 (.097-.140)	637
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	.050 (.030-.070)	.090 (.070-.110)	.120 (.090-.470)	225
	03-04	*	< LOD	< LOD	.049 (.033-.066)	.062 (.048-.100)	241
Non-Hispanic blacks	01-02	*	.040 (<LOD-.080)	.100 (.040-.180)	.180 (.110-.350)	.300 (.170-1.00)	192
	03-04	*	< LOD	.060 (.047-.077)	.100 (.077-.130)	.130 (.110-.160)	264
Non-Hispanic whites	01-02	*	.030 (<LOD-.050)	.080 (.050-.110)	.130 (.090-.210)	.200 (.130-.260)	462
	03-04	*	< LOD	.056 (.046-.067)	.096 (.083-.110)	.130 (.110-.140)	646

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.03 and 0.03.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

clear evidence of an increased risk for reproductive or developmental effects, or cancer (ATSDR, 2007), but increased serum prolactin levels have been correlated with levels of its urinary metabolite (Mutti et al., 1984) and levels of styrene in blood (Luderer et al., 2004) in both male and female workers.

Animal carcinogenicity studies have shown variable results, including lung tumors in mice and no increase in tumor incidence in rats (IARC, 2002). Styrene-7, 8-oxide, a biological metabolite of styrene and also a chemical used in making fragrances and epoxy resins, is classified as a probable human carcinogen by IARC and is reasonably anticipated to be human carcinogen by NTP. Styrene is classified as a possible human carcinogen by IARC. Additional information about external exposure (ie., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of styrene in blood reflect recent exposure. In NHANES 2003-2004 subsample, levels of styrene in blood are of a similar range to those found in a non-representative sample of adults in NHANES III (1988-1994) (Ashley et al., 1994; Churchill et al., 2001). Other small studies of the U.S. general population have reported similar or slightly higher blood styrene levels (Bonanno et al., Buckley, et al., 1997; Sexton et al., 2005 and 2006). Blood styrene levels can be three to fourfold higher in smokers than nonsmokers (Ashley et al., 1995; Bonanno et al., 2001), but exposure to environmental tobacco smoke or vehicle exhaust in urban areas has not been associated with higher blood styrene levels (Bonanno et al., 2001; Romieu et al., 1999). Workers exposed to styrene can have blood levels that are 25 times higher than those in the general population (Brugnone et al., 1993; Triebig et al., 1985).

Finding a measureable amount of styrene in blood does not mean that the level of styrene causes an adverse health effect. Biomonitoring studies of blood styrene can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of styrene than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Toluene

CAS No. 108-88-3

General Information

Toluene (methylbenzene) is a flammable, liquid, aromatic hydrocarbon. It is a high production chemical isolated from crude oil. Toluene is used widely as a solvent and to synthesize chemicals such as benzene, trinitrotoluene, and toluene diisocyanate. As with other aromatic solvents, it is a minor component of gasoline, and additives containing toluene are used as octane boosters. Toluene is detected frequently in urban air, especially in high motor traffic areas and near industrial areas or hazardous waste sites (ATSDR, 2000; Mukund et al., 1996). Indoor air levels of toluene can exceed outdoor levels, largely due to consumer products (e.g., nail polish solvent, adhesive glues, paints, and paint thinner) and cigarette smoke (ATSDR, 2000; Gordon et al., 1999). Toluene does not persist in soil due to its volatility and is not detected commonly in U.S. groundwater and drinking water supplies (USGS, 2006).

The general population is exposed to toluene mainly by breathing contaminated air. Workplace exposure to toluene may occur during the production and use of petrochemicals and solvents. Toluene is well absorbed by inhalation, dermal, and oral exposure routes. After absorption, toluene is metabolized rapidly by hepatic microsomal enzymes, and the major urinary excretion product is hippuric acid. Other urinary metabolites include *ortho*- and *para*-cresol, S-benzylmercapturic acid, and S-*para*-toluylmercapturic acid.

Human health effects from toluene at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Humans exposed to high levels of toluene in air for a short time can show central nervous system depression (lassitude, stupor, and coma). Persons with short term exposures to toluene at levels higher than workplace air standards have shown poor performance on cognitive tests, neurobehavioral impairment, and eye and upper respiratory tract irritation (ATSDR, 2000). Its distinctive aromatic smell is detectable well below workplace air standards. Chronic solvent inhalant abuse, usually involving toluene and other volatile hydrocarbons, has resulted in permanent brain damage with dementia (Filley et al., 2004). Chronic occupational exposures at levels exceeding workplace standards have damaged hearing and possibly color vision (Lomax et al., 2004). In animal studies, prenatal toluene exposure impaired fetal

Blood Toluene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**.156** (.122-.198)	**.160** (.120-.220)	**.340** (.260-.430)	**.670** (.480-.950)	**1.06** (.700-1.43)	954
	03-04	**.114** (.100-.129)	**.096** (.087-.110)	**.220** (.180-.260)	**.430** (.380-.550)	**.680** (.560-.880)	1336
Age group							
20-59 years	01-02	**.156** (.122-.198)	**.160** (.120-.220)	**.340** (.260-.430)	**.670** (.480-.950)	**1.06** (.700-1.43)	954
	03-04	**.114** (.100-.129)	**.096** (.087-.110)	**.220** (.180-.260)	**.430** (.380-.550)	**.680** (.560-.880)	1336
Gender							
Males	01-02	**.165** (.130-.209)	**.170** (.120-.230)	**.360** (.260-.520)	**.780** (.580-1.06)	**1.22** (.850-1.43)	450
	03-04	**.128** (.112-.148)	**.110** (.096-.130)	**.250** (.190-.310)	**.500** (.380-.660)	**.730** (.590-1.10)	647
Females	01-02	**.147** (.114-.190)	**.150** (.110-.220)	**.320** (.240-.390)	**.550** (.400-.740)	**.810** (.530-1.63)	504
	03-04	**.101** (.086-.118)	**.085** (.070-.100)	**.190** (.150-.230)	**.410** (.340-.500)	**.580** (.480-.750)	689
Race/ethnicity							
Mexican Americans	01-02	**.136** (.106-.176)	**.140** (.080-.210)	**.270** (.210-.340)	**.550** (.400-.980)	**.990** (.500-1.30)	219
	03-04	**.084** (.074-.096)	**.076** (.064-.091)	**.120** (.100-.170)	**.280** (.170-.410)	**.400** (.310-.620)	253
Non-Hispanic blacks	01-02	**.137** (.089-.210)	**.150** (.070-.200)	**.310** (.200-.460)	**.690** (.390-1.19)	**1.15** (.660-1.69)	194
	03-04	**.105** (.077-.144)	**.095** (.070-.130)	**.200** (.130-.330)	**.440** (.290-.620)	**.620** (.480-.710)	297
Non-Hispanic whites	01-02	**.165** (.125-.217)	**.170** (.120-.240)	**.350** (.270-.450)	**.710** (.450-1.12)	**1.14** (.710-1.63)	467
	03-04	**.123** (.110-.139)	**.100** (.092-.120)	**.240** (.210-.280)	**.500** (.400-.590)	**.750** (.590-.940)	685

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.025 and 0.025.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.

growth and skeletal development, and altered behavioral development in the offspring (ADSDR, 2000; Jones and Balster, 1997). Evidence for human reproductive effects is inconclusive, and reports of developmental effects have been reported mainly in children exposed *in utero* by maternal solvent abuse (Bukowski, 2001). Epidemiologic studies of workers exposed to toluene (or toluene together with other solvents) have not demonstrated increased risks for cancer, and animal studies have not demonstrated an increased incidence of tumors (IARC, 1999). IARC determined that toluene was not classifiable with regard to human carcinogenicity. The U.S. EPA has established a drinking water and other environmental standards for toluene. The FDA has established a bottle water standard and level for toluene as an indirect food additive. OSHA and ACGIH established workplace standards and guidelines, respectively, for toluene. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of blood toluene reflect recent exposure. A nonrepresentative sample of adults in NHANES III (1988-1994) had geometric mean and median blood toluene levels, respectively, of 0.52 and 0.28 µg/L (Ashley et al., 1994; Churchill et al., 2001), generally higher than comparable levels in NHANES 2001-2002 and 2003-2004. Similar median blood toluene levels have been reported in U.S. children (Sexton et al., 2005, 2006) and in studies of adults without occupational exposure (Backer et al., 1997; Bonanno et al., 2001; Buckley et al., 1997). Population studies in Italy and Mexico have reported median blood toluene levels that were about twice as high as those in the U.S. (Brugnone et al., 1994; Carrer et al., 2000; Lemire et al., 2004; Perbellini et al., 2002). Geometric mean blood toluene levels were 0.191 and 0.669 ng/mL in non-smoking and smoking adults, respectively, from a subsample of NHANES 1999-2000 participants (Lin et al., 2008). Other studies have reported blood toluene levels that were approximately four times higher in smokers than non-smokers (Ashley et al., 1995; Bonanno et al., 2001; Brugnone et al., 1994; Perbellini et al., 2002), but environmental tobacco smoke exposure has not been associated with elevated blood toluene levels (Carrer et al., 2000; Sexton et al., 2005). Exposure to gasoline fumes can increase blood toluene levels during self-service refueling (Backer et al., 1997). Vehicle exhaust and gasoline fumes in such occupational settings as gas stations, automobile repair shops, and street vending can result in blood toluene levels that are two to three times higher than background levels (Mannino et al., 1995; Romieu et al., 1999).

Finding a measureable amount of toluene in blood does not mean that the level of toluene causes an adverse health effect. Biomonitoring studies of blood toluene can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of toluene than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Xylenes

CAS No. 1330-20-7

***o*-xylene** CAS No. 95-47-6

***m*-xylene** CAS No. 108-38-3

***p*-xylene** CAS No. 106-42-3

General Information

Xylenes are aromatic chemicals that exist in three isomeric forms: *o*-, *m*-, and *p*-xylene. Commercial production results in mixed xylenes, which contain these three isomers, in addition to ethylbenzene and trace amounts of several non-xylene hydrocarbons. Specific xylene isomers are produced from mixed xylene and are used to synthesize other chemicals. Mixed xylenes are used widely as gasoline additives; as solvents in manufacturing and laboratory processes; in glues, adhesives, printing inks, paint thinners, and sealants; and as carrier solvents for delivery of some pesticides. Indoor air sources of xylene include building and consumer products, such as adhesives and paints, and also tobacco smoke (ATSDR, 2007). The most important route of exposure for the general population is inhaling volatized xylenes, although dermal contact with liquids containing xylene may also contribute. Workplace exposure to xylenes may occur when producing, transporting, and using petrochemicals and industrial solvents.

Following inhalational, dermal, or oral exposure, xylenes are well absorbed and then rapidly and widely distributed throughout the body tissues, especially adipose tissue. A fraction of an absorbed xylene dose is excreted unchanged in exhaled air, and about 90% of a dose is metabolized by the liver and then eliminated in urine over several days. Methylhippuric acids are the predominant urinary metabolites and have been used to monitor workplace exposures.

Human health effects from xylenes at low environmental doses or at biomonitored levels from low environmental exposures are unknown. Among humans, accidental exposure to high levels of xylene in air can cause eye and mucous membrane irritation, dyspnea, and central nervous system effects, such as headaches, dizziness, forgetfulness, delayed reaction times, and poor coordination (ATSDR, 2007). Epidemiologic studies of cancer and xylene exposure have been inconclusive and are limited by small numbers, lack of exposure measurements, and the concomitant

Blood *o*-Xylene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	*	< LOD	**.070** (.050-.080)	**.100** (.080-.130)	**.130** (.110-.180)	981
	03-04	*	< LOD	**.051** (<LOD-.057)	**.072** (.066-.079)	**.090** (.081-.097)	1365
Age group							
20-59 years	01-02	*	< LOD	**.070** (.050-.080)	**.100** (.080-.130)	**.130** (.110-.180)	981
	03-04	*	< LOD	**.051** (<LOD-.057)	**.072** (.066-.079)	**.090** (.081-.097)	1365
Gender							
Males	01-02	*	< LOD	**.070** (.050-.090)	**.110** (.080-.140)	**.150** (.110-.180)	465
	03-04	*	< LOD	**.057** (.050-.060)	**.074** (.068-.084)	**.096** (.084-.110)	667
Females	01-02	*	< LOD	**.060** (.050-.080)	**.100** (.070-.130)	**.120** (.100-.180)	516
	03-04	*	< LOD	< LOD	**.067** (.059-.076)	**.085** (.074-.095)	698
Race/ethnicity							
Mexican Americans	01-02	*	< LOD	**.060** (<LOD-.080)	**.090** (.080-.110)	**.120** (.090-.270)	227
	03-04	*	< LOD	**.052** (<LOD-.067)	**.074** (.067-.080)	**.100** (.075-.130)	265
Non-Hispanic blacks	01-02	*	< LOD	**.050** (<LOD-.070)	**.100** (.080-.110)	**.110** (.100-.160)	197
	03-04	*	< LOD	< LOD	**.065** (.055-.078)	**.084** (.068-.100)	301
Non-Hispanic whites	01-02	*	< LOD	**.070** (.050-.090)	**.110** (.080-.140)	**.140** (.110-.180)	483
	03-04	*	< LOD	**.052** (<LOD-.058)	**.073** (.066-.082)	**.090** (.081-.100)	694

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.049 and 0.049.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.
< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample.
* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

exposure to other solvents (IARC, 1999). Animal studies involving high doses showed hepatic enzyme induction, liver enlargement, increased kidney weight and renal cytochrome P450 content, as well as neurobehavioral effects and altered catecholamine levels in the brain (ATSDR 2007). Pregnant animals that inhaled high doses had increased fetal resorptions and offspring with skeletal abnormalities and decreased body weight (ATSDR 2007). Neurobehavioral effects resulted in laboratory animals exposed during gestation to xylene concentrations in the air that were about five times higher than U.S. occupational standards (Hass et al., 1997,1995). Animals exposed to high doses of technical grade xylene by gavage did not demonstrate an increase in the incidence of tumors (NTP, 1986).

Workplace standards for xylene levels in air have been established by OSHA, and ACGIH recommends a biological exposure index to monitor workplace exposure. The U.S. EPA has established a drinking water standard and other environmental standards for xylene. FDA has established a bottled drinking water standard. IARC has determined that xylene is not classifiable with regard to its human carcinogenicity. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR at: http://www.atsdr.cdc.gov/toxpro2.html.

Biomonitoring Information

Levels of blood xylenes reflect recent exposure. The *m*- and *p*- xylene isomers usually are measured together and reported as *m*/*p*-xylene; the *o*-xylene isomer is measured and reported separately. In the NHANES 2001-2002 and 2003-2004 subsamples, blood *o*-xylene was nondetectable in a majority of the participants, whereas the median blood *m*/*p*-xylene levels were similar to the earlier NHANES III results. In a nonrepresentative subsample of adults in NHANES III (1988-1994), the median blood levels of *o*-xylene and *m*/*p*-xylene were 0.11 µg/L and 0.19 µg/L, respectively (Ashley et al., 1994). These results were roughly similar to geometric mean levels of nonsmokers reported in a subsample of NHANES 1999-2000 (Lin et al., 2008) and in other studies of the U.S. general population (Bonanno et al., 2001; Buckley et al., 1997; Hamar et al., 1996), and to levels in adults in other countries (Lemire et al., 2002). Blood *o*-xylene levels in U.S. children were two to three times lower than adult levels (Sexton et al., 2005, 2006). Smokers can have blood *o*- and *m*/*p*-xylene levels that are each about twice as high as those for nonsmokers (Ashley et al., 1995; Bonanno et al., 2001; Lin et al., 2008).

Blood *m*- and *p*-Xylene

Geometric mean and selected percentiles of blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey.

	Survey years#	Geometric mean (95% conf. interval)	Selected percentiles (95% confidence interval) 50th	75th	90th	95th	Sample size
Total	01-02	**.156** (.124-.198)	**.150** (.110-.200)	**.280** (.190-.430)	**.500** (.370-.690)	**.670** (.500-.890)	962
	03-04	**.136** (.123-.150)	**.130** (.120-.150)	**.200** (.190-.210)	**.280** (.260-.300)	**.340** (.310-.400)	1346
Age group							
20-59 years	01-02	**.156** (.124-.198)	**.150** (.110-.200)	**.280** (.190-.430)	**.500** (.370-.690)	**.670** (.500-.890)	962
	03-04	**.136** (.123-.150)	**.130** (.120-.150)	**.200** (.190-.210)	**.280** (.260-.300)	**.340** (.310-.400)	1346
Gender							
Males	01-02	**.155** (.121-.200)	**.140** (.110-.190)	**.280** (.180-.440)	**.510** (.350-.700)	**.700** (.500-.890)	455
	03-04	**.149** (.134-.166)	**.140** (.130-.170)	**.220** (.200-.230)	**.290** (.270-.320)	**.380** (.300-.490)	654
Females	01-02	**.157** (.124-.199)	**.150** (.110-.220)	**.270** (.190-.410)	**.480** (.360-.650)	**.650** (.460-.890)	507
	03-04	**.124** (.112-.138)	**.130** (.110-.140)	**.180** (.160-.200)	**.270** (.240-.300)	**.340** (.290-.390)	692
Race/ethnicity							
Mexican Americans	01-02	**.134** (.097-.184)	**.130** (.090-.180)	**.240** (.150-.370)	**.400** (.290-.540)	**.540** (.380-1.10)	223
	03-04	**.132** (.109-.160)	**.120** (.110-.150)	**.180** (.140-.230)	**.250** (.220-.320)	**.360** (.260-.490)	257
Non-Hispanic blacks	01-02	**.147** (.107-.202)	**.140** (.090-.220)	**.280** (.160-.460)	**.470** (.330-.850)	**.590** (.420-1.08)	198
	03-04	**.117** (.094-.146)	**.120** (.099-.140)	**.170** (.140-.220)	**.270** (.210-.330)	**.330** (.260-.450)	297
Non-Hispanic whites	01-02	**.163** (.124-.214)	**.160** (.110-.220)	**.300** (.190-.480)	**.520** (.370-.740)	**.700** (.510-.960)	468
	03-04	**.141** (.128-.155)	**.140** (.130-.150)	**.210** (.190-.220)	**.290** (.270-.310)	**.350** (.330-.400)	690

Limits of detection (LOD, see Data Analysis section) for Survey years 01-02 and 03-04 are 0.034 and 0.034.
Survey period 2001-2002 is a one-third subsample of 20-59 year olds; Survey period 2003-2004 is a one-half subsample of 20-59 year olds.

Workers who are exposed to vehicle exhaust can have *o*- and *m*/*p*-xylene blood levels that are each about two to three times higher than levels in the general population (Backer et al., 1997; Mannino et al., 1995; Romieu et al., 1999).

Finding a measurable amount of any of the xylenes in blood does not mean that the level of xylene causes an adverse health effect. Biomonitoring studies of blood xylenes can provide physicians and public health officials with reference values so that they can determine whether or not people have been exposed to higher levels of xylenes than levels found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects.

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Appendix A. Procedure to Estimate Percentiles

Including percentiles whose estimate falls on a value that is repeated multiple times in the dataset

A common practice to calculate confidence intervals from survey data is to use large-sample normal approximations. Ninety-five percent confidence intervals on point estimates of percentiles are often computed by adding and subtracting from the point estimate a quantity equal to twice its standard error. This normal approximation method may not be adequate, however, when estimating the proportion of subjects above or below a selected value, especially when the proportion is near 0.0 or 1.0 or when the effective sample size is small. In addition, confidence intervals on proportions deviating from 0.5 are not theoretically expected to be symmetric around the point estimate. Further, adding and subtracting a multiple of the standard error to an estimate near 0.0 or 1.0 can lead to impossible confidence limits (i.e., proportion estimates below 0.0 or above 1.0). The approach used for the *Report* data tables (and for previous *Reports*) produces asymmetric confidence intervals consistent with skewed (nonnormal) biologic data distributions.

The method we use to estimate percentiles and their confidence limits for the *Report* data tables and for previous reports is adapted from a method proposed by Woodruff (1952) for percentile estimation and a method described by Korn and Graubard (1998) for estimating confidence intervals for proportions. This method essentially involves first obtaining an empirical point estimate of the desired percentile by creating a rank ordered listing of the sampled observations along with their sampling weights. From this listing and the sampling weights, it is possible to determine an empirical percentile estimate for the target population. After this point estimate of the percentile has been obtained, the fraction of results below the estimate is calculated. The fraction below the point estimate should be very close to the proportion corresponding to the desired percentile, but can deviate from this proportion depending on the frequency of non-unique sampled observations in the vicinity of the empirical percentile estimate and depending on the sampling weight associated with the sampled observation. For example, when measuring some compounds as part of NHANES there may be multiple results below a common limit of detection (LOD) or multiple results with identical measured values due to the reporting limitations of the instrument. This phenomenon coupled with the sampling weight assigned to each measured result and with the limitations of statistical software can lead to difficulties in accurately estimating some percentiles and their corresponding confidence limits because an exact percentile may fall within a large group of results with identical measured values. We circumvented this potential problem for the *Report* data tables by adding a unique, negligibly small number to each measured result. This small number was later subtracted from the percentile estimate without affecting the percentile estimate and without altering any of the original measured results.

By adding a unique, negligibly small number to each sampled observation, it was possible to associate a single sampled observation with the percentile estimate and thus to minimize the difference between the fraction below the point estimate and the proportion corresponding to the desired percentile. However, due to sample weighting, it is still possible to obtain a different point estimate (which will only differ by the difference between numerically adjacent analyte values) depending on how the data are sorted before adding the unique number to each result. We circumvented this potential problem by replacing actual sample weights with an average sample weight where the average is computed across subjects in the same demographic domain who have identical measured results. We computed standard error estimates in a separate step using the original (unaltered) data. Clopper-Pearson 95% confidence intervals around the estimated proportion are obtained using the method described by Korn and Graubard (1998).

We describe below how SAS Proc Univariate and SUDAAN can be used to carry out this method of percentile and confidence interval estimation. SAS code for calculating these confidence intervals can be downloaded from http://www.cdc.gov/exposurereport. In the narrative that follows, the term 'demographic domain' refers to a demographic group of interest, for example non-Hispanic blacks. The term 'set of subsample weights' refers to the sampling weights that correspond to the variable for which percentiles will be estimated, for example the set of subsample weights associated with total blood mercury measurements. The term 'analyte' refers to the biological or chemical compound measured in a group of subjects and for which percentiles are to be estimated.

Procedure to calculate percentile estimates and their confidence intervals

Step 1: Obtain a percentile estimate using the original (unaltered data):
Create a separate file with original data (ORIG_DATA). Use SAS (SAS Institute Inc. 1999) Proc Univariate (with default percentile definition equivalent to option PCTLDEF = 5 and with the Freq option variable equal to the original subsample sampling weight) to obtain a point estimate of the percentile (PTLE_ORIG) of an analyte's original results for the demographic domain of interest, for example, the 90th percentile of blood lead results for children aged 1-5 years.

Step 2: Obtain a percentile estimate using the altered data:
Create a separate file for use with altered data (ALTR_DATA). Sort the data by analyte measured value separately for each particular demographic domain and set of subsample weights. Use SAS Proc Means to compute the average sampling weight (WT_{AVE}) for each unique measured result. For each unique measured result, use a counter from 1 to the total number of subjects with identical values to create a unique integer to associate with each measured observation. Each of these numbers should then be divided by 1,000,000,000 and added to the corresponding measured observation. This will result in each measured observation having an additional fractional amount beyond the fourth decimal as long as there are less than 10,000 subjects with the same measured result. Use SAS Proc Univariate (again with default percentile definition equivalent to option PCTLDEF = 5 but now with the Freq option variable equal to WT_{AVE}) to obtain a point estimate of the percentile (PTLE_ALTR) of an analyte's altered results for the demographic domain of interest.

Step 3: Sort the data in the ORIG_DATA file by the stratum (sdmvstra) and primary sampling unit (sdmvpsu) variables. Use SUDAAN (SUDAAN Users Manual, 2001) Proc Descript with Taylor Linearization DESIGN = WR (i.e., sampling with replacement), with proper NEST statement, and with the original subsample sampling weight variable to estimate the proportion (P_ORIG) of subjects with results below the percentile estimate (PTLE_ORIG) obtained in Step 1 and discard P_ORIG but retain the standard error (SEMEAN_ORIG) associated with PTLE_ORIG.

Step 4: Sort the data in the ALTR_DATA file by the stratum (sdmvstra) and primary sampling unit (sdmvpsu) variables. Use SUDAAN (SUDAAN Users Manual, 2001) Proc Descript with Taylor Linearization DESIGN = WR (i.e., sampling with replacement), with proper NEST statement, and with the average sampling weight variable (WT_{AVE}) to estimate the proportion (P_ALTR) of subjects with results below the percentile estimate (PTLE_ALTR) obtained in Step 2 and keep P_ALTR but discard the standard error (SEMEAN_ALTR) associated with PTLE_ALTR. Compute the degrees-of-freedom adjusted effective sample size.

(1) $n_{df} = ((t_{num}/t_{denom})^2)P\_ALTR(1 - P\_ALTR)/(SEMEAN\_ORIG^2)$

where t_{num} and t_{denom} are 0.975 critical values of the Student's t distribution with degrees of freedom equal to the actual sample size minus 1 and the number of primary sampling units (PSUs) minus the number of strata, respectively. Note: the degrees of freedom for t_{denom} can vary with the demographic domain of interest (e.g., males).

Step 5: After obtaining an estimate of P_ALTR (i.e., the proportion obtained in Step 4), compute the Clopper-Pearson 95% confidence interval ($P_L(x,n_{df})$, $P_U(x,n_{df})$) as follows:

(2) $P_L(x,n_{df}) = v_1F_{v1,v2}(0.025)/(v_2 + v_1F_{v1,v2}(0.025))$ & $P_U(x,n_{df}) = v_3F_{v3,v4}(0.975)/(v_4 + v_3F_{v3,v4}(0.975))$

where x is equal to P_ALTR times n_{df}, $v_1 = 2x$, $v_2 = 2(n_{df} - x + 1)$, $v_3 = 2(x + 1)$, $v_4 = 2(n_{df} - x)$, and $F_{d1,d2}(\beta)$ is the β quantile of an F distribution with d_1 and d_2 degrees of freedom. (Note: If n_{df} is greater than the actual sample size or if P_ALTR is equal to zero, then the actual sample size should be used.) This step will produce a lower and an upper limit for the estimated proportion obtained in Step 4.

Step 6: Use SAS Proc Univariate (again with default percentile definition equivalent to option PCTLDEF = 5 and with the Freq option variable equal to WT_{AVE}) to determine the analyte values that correspond to the desired percentile (proportion) and the lower and upper proportion limits obtained in Step 5. Round these results to 2 or 3 decimals depending on the significant figures associated with the original measured values.

Example:

To estimate the 75th percentile of blood lead in children age 1-5 years in the 2003-2004 survey, create two separate files: name one ORIG_DATA and the other ALTR_DATA. For the ORIG_DATA file use SAS Proc Univariate with the Freq option and the subsample sampling weight (or in this case the full sample sampling weight because blood lead is the analyte of interest) to get a weighted point estimate of the analyte value that corresponds to the 75^{th} percentile (PTLE_ORIG). For this example the value is 2.5 µg/dL.

Sort the results in the ALTR_DATA file by analyte measured value. Use SAS Proc Means to compute the average sampling weight (WT_{AVE}) for each unique analyte measured value. For each unique measured result, use a counter from 1 to the total number of subjects with identical values to create a unique integer to associate with each measured observation. Divide each counter value by 1,000,000,000 and add this amount to the corresponding measured observation. For this altered data file (ALTR_DATA) use SAS Proc Univariate with the Freq option and WT_{AVE} to get a weighted point estimate of the analyte value that corresponds to the 75^{th} percentile (PTLE_ALTR). For this example the value is also 2.5 µg/dL.

For the ORIG_DATA file use SUDAAN to estimate the weighted proportion (P_ORIG) of subjects with results below the value of PTLE_ORIG (which can differ from 0.75 depending on the number of results with identical values; for this example the proportion is 0.7374) and the standard error (SEMEAN_ORIG) associated with P_ORIG (for this example SEMEAN_ORIG = 0.0237).

For the ALTR_DATA file use SUDAAN to estimate the weighted proportion of subjects (P_ALTR) with results below the value of PTLE_ALTR (which should also be very close to 0.75 regardless of the number of original results with identical values; for this example the proportion is 0.7497). Then obtain a confidence interval on P_ALTR by computing the weighted Clopper-Pearson 95% confidence limits (equation 2 above) using the degrees-of-freedom adjusted effective sample size as described in equation 1 above. For this example the effective sample size is 283.911 resulting in lower and upper confidence limits of 0.6951 and 0.7990, respectively. Then use SAS Proc Univariate (with the Freq option variable equal to WT_{AVE}) to determine the analyte values corresponding to the weighted 69.5^{th} and 79.9^{th} percentiles. These point estimates are the lower and upper confidence limits on the 75th percentile estimate. Round the 75^{th} percentile estimate and its confidence limits to 2 or 3 decimals depending on the significant figures associated with the original measured values. For this example the rounded point estimate is 2.5 µg/dL with lower and upper confidence limits of 2.3 and 2.8 µg/dL, respectively.

Note: Previous reports of the analyses of 1999-2000 data (in the *Second National Report on Human Exposure to Environmental Chemicals*) used a jackknife method (available within SUDAAN) for variance estimation that was based on replicate weights. To better address multiple 2-year data sets and to combine 2-year data sets into 4-year data sets, NCHS developed a new approach based on masked variance units that uses a Taylor series (linearization) method that is also available in SUDAAN. The two methods produce very similar, but not identical, variance estimates. In the *Third National Report on Human Exposure to Environmental Chemicals* and in the current *Report* data tables, all variance estimates (1999-2000, 2001-2002, 2003-2004) were calculated using the Taylor series (linearization) method within SUDAAN.

Appendix B. Changes and Edits to Results Released in the *Third Report*

Some biomonitoring results from earlier NHANES survey periods require corrections due to analytical issues. Corrections can include changes in specific data tables or the removal of data tables in this *Report*, as compared to the previous *Third National Report on Human Exposure to Environmental Chemicals*. The following chemical tables are affected:

1. The data for *beta*-hexachlorocyclohexane serum levels (lipid adjusted and whole weight) in the *Third National Report on Human Exposure to Environmental Chemicals* for the NHANES survey period 2001-2002 should have been adjusted by multiplying each data point by a factor of 1.5528. The data for this chemical in the current *Report* have had this adjustment applied. This adjustment was needed due to a misassignment of the concentration of a purchased standard material.

2. Urinary 2,4-dichlorophenol and 2,5-dichlorophenol were presented in the *Third National Report on Human Exposure to Environmental Chemicals* for the years 1999-2002 and have been removed from this *Report* due to matrix-based calibration biases. Data Tables for these two chemicals in the 2003-2004 survey period will be included in the next release of the *Report*.

3. Improvements in analytical methods have resulted in dropping data for some urinary Polycyclic Aromatic Hydrocarbon (PAH) metabolites. For the 1999-2000 survey period, urinary data for 2-hydroxyfluorene, 3-hydroxyfluorene, 1-hydroxyphenanthrene, 2-hydroxyphenanthrene, 3-hydroxyphenanthrene, and 1-hydroxypyrene have been removed from the Data Tables in the current *Report*. The data from 1999-2000 for these specific analytes are not in agreement with current methods -- specifically interferences in some analytical peaks have been detected with newer analytic methods and newer techniques have shown that deconjugation in the analytical method was not complete for some PAHs. For the 1999-2002 period, data for urinary metabolites of 1-Hydroxybenz[a]anthracene, 3-hydroxybenz[a]anthracene, 9-Hydroxybenz[a]anthracene, 1-Hydroxybenzo[c]phenanthrene, 2-Hydroxybenzo[c]phenanthrene, 3-Hydroxybenzo[c]phenanthrene, 1-Hydroxychrysene, 2-Hydroxychrysene, 3-Hydroxychrysene, 4-Hydroxychrysene, 6-Hydroxychrysene and 3-Hydroxybenzo[a]pyrene have been removed and are not planned for future *Reports*. Improvements in analytical methods have found uncertainties due to interferences in accurate mass detection in the previous method. In addition, data for 3-Hydroxybenzo[a]pyrene in the 2001-2002 survey period has been removed due to an interference in a purchased reagent used in the deconjugation step of the analytical method.

Data for three additional PAH urinary metabolites have been removed for the 1999-2002 survey period. Urinary 9-hydroxyphenanthrene has been removed due to degradation during the deconjugation step of the analytical method. Urinary 9-hydroxyphenanthrene will not be reported in future survey periods. Urinary 9-hydroxyfluorene has been removed due to an incomplete deconjugation step revealed by improved methods. Data for urinary 9-hydroxyfluorene *is* reported in the 2003-2004 survey period. Urinary 4-hydroxyphenanthrene has been removed as a result of infrequent interferences in the analytical method, which were detected by an improved analytical method. Urinary 4-Hydroxyphenanthrene *is* reported in the 2003-2004 survey period.

Data for three urinary PAH metabolites from the 2001-2002 survey are under current evaluation and do not appear in this release of the *Report*: 1-hydroxynaphthalene, 2-hydroxyfluorene, and 1-hydroxypyrene.

Appendix C. References for Biomonitoring Analytical Methods

Acrylamide Adducts

Vesper HW, Bernert JT, Ospina M, Meyers T, Ingham L, Smith A, et al. Assessment of the relation between biomarkers for smoking and biomarkers for acrylamide exposure in humans. Cancer Epidemiol Biomarkers Prev 2007;16(11):2471-2478.

Vesper HW, Slimani N, Hallmans G, Tjonneland A, Agudo A, Benetou V, et al. Cross-sectional study on acrylamide hemoglobin adducts in subpopulations from the European Prospective Investigation into Cancer and Nutrition (EPIC) study. J Agric Food Chem 2008; 56 (15):6046–6053.

Cotinine

Bernert JT, McGuffey JE, Morrison MA, Pirkle JL. Comparison of serum and salivary cotinine measurements by a sensitive high-performance liquid chromatography/tandem mass spectrometry method as an indicator of exposure to tobacco smoke among smokers and nonsmokers. J Anal Toxicol 2000;24:333-339.

Bernert JT, Turner WE, Pirkle JL, Sosnoff CS, Akins JR, Waldrep MK, et al. Development and validation of a sensitive measurement of serum cotinine in both smokers and nonsmokers by liquid chromatography/atmospheric pressure ionization tandem mass spectrometry. Clin Chem 1997;43:2281-2291.

N,N-Diethyl-meta-toluamide (DEET)

Olsson AO, Baker SE, Nguyen JV, Romanoff LC, Udunka SO, Walker RD, et al. A liquid chromatography-tandem mass spectrometry multiresidue method for quantification of specific metabolites of organophosphorus pesticides, synthetic pyrethroids, selected herbicides, and DEET in human urine. Anal Chem 2004;76(9):2453-2461.

Disinfection By-Products (Trihalomethanes)

Blount BC, Kobelski RJ, McElprang DO, Ashley DL, Morrow JC, Chambers DM, et al. Quantification of 31 volatile organic compounds in whole blood using solid-phase microextraction and gas chromatography-mass spectrometry. J Chromatogr B Analyt Technol Biomed Life Sci 2006;832: 292-301.

Environmental Phenols

Ye X, Kuklenyik Z, Needham LL, Calafat AM. Automated on-line column-switching HPLC-MS/MS method with peak focusing for the determination of nine environmental phenols in urine. Anal Chem 2005;77:5407-5413.

Fungicides

Hill RH Jr, Shealy DB, Head SL, Williams CC, Bailey SL, Gregg M, et al. Determination of pesticide metabolites in human urine using isotope dilution technique and tandem mass spectrometry. J Anal Toxicol 1995;19(5):323-329.

Bravo R, Caltabiano LM, Fernandez C, Smith KD, Gallegos M, Whitehead RD, et al. Quantification of phenolic metabolites of environmental chemicals in human urine using gas chromatography-tandem mass spectrometry and isotope dilution quantification. J Chromatog B 2005;820(2):229-236.

Herbicides

Bravo R, Caltabiano LM, Fernandez C, Smith KD, Gallegos M, Whitehead RD, et al. Quantification of phenolic metabolites of environmental chemicals in human urine using gas chromatography-tandem mass spectrometry and isotope dilution quantification. J Chromatog B 2005;820(2):229-236.

Hill RH Jr, Shealy DB, Head SL, Williams CC, Bailey SL, Gregg M, et al. Determination of pesticide metabolites in human urine using isotope dilution technique and tandem mass spectrometry. J Anal Toxicol 1995;19(5):323-329.

Olsson AO, Baker SE, Nguyen JV, Romanoff LC, Udunka SO, Walker RD, et al. A liquid chromatography-tandem mass spectrometry multiresidue method for quantification of specific metabolites of organophosphorus pesticides, synthetic pyrethroids, selected herbicides, and DEET in human urine. Anal Chem 2004;76(9):2453-2461.

Insecticides and Pesticides

Carbamate Insecticides

Bravo R, Caltabiano LM, Fernandez C, Smith KD, Gallegos M, Whitehead RD, et al. Quantification of phenolic metabolites of environmental chemicals in human urine using gas chromatography-tandem mass spectrometry and isotope dilution quantification. J Chromatog B 2005;820(2):229-236.

Hill RH Jr, Shealy DB, Head SL, Williams CC, Bailey SL, Gregg M, et al. Determination of pesticide metabolites in human urine using isotope dilution technique and tandem mass spectrometry. J Anal Toxicol 1995;19(5):323-329.

Organochlorines Pesticides

Barr JB, Maggio VL, Barr DB, Turner WE, Sjödin A, Sandau CD, et al. New high-resolution mass spectrometric approach for the measurement of polychlorinated biphenyls and organochlorine pesticides in human serum. J Chromatog B 2003;794:137-148.

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Turner WE, DiPietro E, Lapeza CR, Jr., Green V, Gill J, Patterson DG Jr., et al. Universal automated cleanup system for the isotope-dilution high-resolution mass spectrometric analysis of PCDDs, PCDFs, coplanar PCBs, PCB congeners, and persistent pesticides from the same serum sample. Organohalogen Compounds 1997;31:26-31.

Organophosphate Insecticides: Dialkyl Phosphate Metabolites

Bravo R, Caltabiano LM, Weerasekera G, Whitehead RD, Fernandez C, Needham LL, et al. Measurement of dialkyl phosphate metabolites of organophosphorus pesticides in human urine using lyophilization with gas chromatography-tandem mass spectrometry and isotope dilution quantification. J Expo Anal Environ Epidemiol 2004;14:249-259.

Bravo R, Driskell WJ, Whitehead RD Jr, Needham LL, Barr DB. Quantitation of dialkyl phosphate metabolites of organophosphate pesticides in human urine using GC-MS-MS with isotopic internal standards. J Anal Toxicol 2002;26:245-252.

Organophosphate Insecticides: Specific Metabolites

Bravo R, Caltabiano LM, Fernandez C, Smith KD, Gallegos M, Whitehead RD, et al. Quantification of phenolic metabolites of environmental chemicals in human urine using gas chromatography-tandem mass spectrometry and isotope dilution quantification. J Chromatog B 2005;820(2):229-236.

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Olsson AO, Baker SE, Nguyen JV, Romanoff LC, Udunka SO, Walker RD, et al. A liquid chromatography-tandem mass spectrometry multiresidue method for quantification of specific metabolites of organophosphorus pesticides, synthetic pyrethroids, selected herbicides, and DEET in human urine. Anal Chem 2004;76(9):2453-2461.

Pyrethroid Pesticides

Olsson AO, Baker SE, Nguyen JV, Romanoff LC, Udunka SO, Walker RD, et al. A liquid chromatography-tandem mass spectrometry multiresidue method for quantification of specific metabolites of organophosphorus pesticides, synthetic pyrethroids, selected herbicides, and DEET in human urine. Anal Chem 2004;76(9):2453-2461.

Metals

Caldwell KL, Hartel J, Jarrett J, Jones RL. Inductively coupled plasma mass spectrometry to measure multiple toxic elements in urine in NHANES 1999-2000. Atomic Spectroscopy. 2005;26(1):1-7.

Chen HP, Paschal DC, Miller DT, Morrow JC. Determination of total and inorganic mercury in whole blood by on-line digestion with flow injection. Atomic Spectroscopy 1998;19:176-179.

Jarrett JM, Jones RL, Caldwell KL, Verdon CP. Total urine arsenic measurements using inductively coupled plasma mass spectrometry with a dynamic reaction cell. Atomic Spectroscopy 2007;28(4):113-122.

Miller, DT, Paschal DC, Gunter EW, Stroud PE, D'Angelo J. Determination of lead in blood using electrothermal atomization atomic absorption spectrometry with a L'vov platform and matrix modifier. Analyst 1987;112:1701-1704.

Paschal DC, Ting BG, Morrow JC, Pirkle JL, Jackson RJ, Sampson EJ, et al. Trace metals in urine of United States residents: reference range concentrations. Environ Res 1998;76:53-59.

Stoeppler M, Brandt K. Determination of cadmium in whole blood and urine by electrothermal atomic-absorption spectrophotometry. Fresnius A Anal Chem 1980;300:372-380.

Verdon CP, Caldwell KL, Fresques MR, Jones RL. Determination of seven arsenic compounds in urine by HPLC-ICP-DRC-MS: a CDC population biomonitoring method. Anal Bioanal Chem 2008;393(3):939-947.

Perchlorate

Valentin-Blasini L, Blount BC, Delinsky A. Quantification of iodide and sodium-iodide symporter inhibitors in human urine using ion chromatography tandem mass spectrometry. J Chrom A 2007;1155(1):40-46.

Valentin-Blasini L, Mauldin JP, Maple D and Blount BC. Analysis of perchlorate in human urine using ion chromatography and electrospray tandem mass spectrometry. Anal Chem 2005;77(8):2475-2481.

Perfluorochemicals

Kuklenyik Z, Needham LL, Calafat AM. Measurement of 18 perfluorinated organic acids and amides in human serum using on-line solid-phase extraction. Anal Chem 2005;77:6085-6091.

Phthalates

Blount BC, Milgram KE, Silva M, Malek N, Reidy J, Needham LL, et al. Quantitative detection of eight phthalate metabolites in human urine using HPLC-APCI-MS/MS. Anal Chem 2000;72:4127-4134.

Silva MJ, Malek NA, Hodge CC, Reidy JA, Kato K, Barr DB, et al. Improved quantitative detection of 11 urinary phthalate metabolites in humans using liquid chromatography-atmospheric pressure chemical ionization tandem mass spectrometry. J Chromatog B 2003;789:393-404.

Silva MJ, Slakman AR, Reidy JA, Preau JLJ, Herbert AR, Samandar E, et al. Analysis of human urine for 15 phthalate metabolites using automated solid-phase extraction. J Chromatog B 2004;805:161-167.

Phytoestrogens

Valentin-Blasini L, Blount BC, Rogers HS, Needham LL. HPLC-MS/MS method for the measurement of seven phytoestrogens in human serum and urine. J Expo Anal Environ Epidemiol 2000;10:799-807.

Kuklenyik Z, Ye X, Reich JA, Needham LL, Calafat AM. Automated on-line and off-line solid phase extraction methods for measuring isoflavones and lignans in urine. J Chromatogr Sci 2004; 42:495-500.

Polybrominated Diphenyl Ethers and 2,2’,4,4’,5,5’-Hexabromobiphenyl

Sjödin A, Jones RS, Lapeza CR, Focant J-F, McGahee EE III, Patterson DG. Semiautomated high-throughput extraction and cleanup method for the measurement of polybrominated diphenyl ethers, polybrominated biphenyls, and polychlorinated biphenyls in human serum. Anal Chem 2004;76:1921-1927.

Polychlorinated Biphenyls, Polychlorinated Dibenzo-*p*-dioxins, Dibenzofurans

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Polycyclic Aromatic Hydrocarbons

Li Z, Romanoff LC, Young KJ, Blakely NC III, Wei RW, Needham LL, et al. Biomonitoring of human exposure to polycyclic aromatic hydrocarbons (PAH) and diesel exhaust by measurement of urinary biomarkers. Epidemiology 2004;15(4):S75.

Romanoff LC, Li Z, Young KJ, Blakely NC III, Patterson DG, Sandau CD. Automated solid-phase extraction method for measuring urinary polycyclic aromatic hydrocarbon metabolites in human biomonitoring using isotope-dilution gas chromatography high-resolution mass spectrometry. J Chromatog B 2006;835:47-54.

Smith CJ, Huang WL, Walcott CJ, Turner WE, Grainger J, Patterson DG Jr. Quantification of monohydroxy-PAH metabolites in urine by solid-phase extraction with isotope dilution GC-HRMS. Anal Bioanal Chem 2002;372:216-220.

Volatile Organic Compounds

Blount B.C, Kobelski R.J, McElprang D.O, Ashley D.L, Morrow J.C, Chambers D.M, et al. Quantification of 31 volatile organic compounds in whole blood using solid-phase microextraction and gas chromatography-mass spectrometry. J Chromatogr B Analyt Technol Biomed Life Sci 2006;832: 292-301.

Appendix D. Limit of Detection Table

The analytical limit of detection (LOD) for each of the different chemical measurements is presented in the table below. The LOD is the level at which the measurement has a 95% probability of being greater than zero (Taylor, 1987). For most chemicals, the LOD is constant for each sample analyzed. However, for dioxins, furans, PCBs, organochlorine insecticides, and some other pesticides, each individual sample has its own LOD. These analyses have an individual LOD for each sample, mostly because the sample volume available for analysis differed for each sample. A higher sample volume results in a lower LOD and a better ability to detect low levels.

For chemicals with sample-specific LODs, we report in the table the maximum LOD among the samples analyzed. In general, the average LOD for these samples is about 40-50% of the maximum LOD. If a geometric mean or percentile estimate is less than the maximum LOD, it is noted in the results tables, and we do not report a number for that estimate. This conservative approach is to assure high confidence in all number reported in the results tables.

As analytical methods improve, LODs will often change. For this reason, LOD results are reported by survey periods (e.g., 1999-2000, 2001-2002, 2003-2004).

Reference: Taylor JK. *Quality Assurance of Chemical Measurements.* Chelsea (MI): Lewis Publishing. 1987.

Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Acrylamide Adducts					
Acrylamide	blood	pmol/g hemoglobin			3.0
Glycidamide	blood	pmol/g hemoglobin			4.0
Cotinine	serum	ng/mL	0.05	0.05	0.015
N,N-Diethyl-*meta* -toluamide (DEET)	urine	µg/L	0.449	0.1	
Disinfection By-Products (Trihalomethanes)					
Bromodichloromethane	blood	pg/mL		0.233	0.62
Dibromochloromethane (Chlorodibromomethane)	blood	pg/mL		0.271	0.62
Tribromomethane (Bromoform)	blood	pg/mL		0.596	1.5
Trichloromethane (Chloroform)	blood	pg/mL		2.37	2.11

Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Environmental Phenols					
Bisphenol A (2,2-*bis* [4-Hydroxyphenyl] propane)	urine	µg/L			0.4
Benzophenone-3 (2-Hydroxy-4-methoxybenzophenone)	urine	µg/L			0.3
4-*tert*-Octylphenol (4-[1,1,3,3-Tetramethylbutyl] phenol)	urine	µg/L			0.2
Triclosan (2,4,4'-Trichloro-2'-hydroxyphenyl ether)	urine	µg/L			2.3
Fungicides and Metabolites					
Pentachlorophenol	urine	µg/L	0.25	0.5	
ortho-Phenylphenol	urine	µg/L	0.3	0.3	
Herbicides and Metabolites					
Acetochlor mercapturate	urine	µg/L		0.1	
Alachlor mercapturate	urine	µg/L	1.18		
Atrazine mercapturate	urine	µg/L	0.791	0.3	
2,4-Dichlorophenoxyacetic acid	urine	µg/L	0.952	0.2	
Metolachlor mercapturate	urine	µg/L		0.2	
2,4,5-Trichlorophenoxyacetic acid	urine	µg/L	1.2	0.1	
Insecticides and Metabolites					
Carbamates					
Carbofuranphenol	urine	µg/L	0.4	0.4	
2-Isopropoxyphenol	urine	µg/L	1.1	0.4	
Organochlorines and Metabolites					
Aldrin	serum	ng/g of lipid		5.94	7.8
o,p'-Dichlorodiphenyltrichloroethane	serum	ng/g of lipid	20.7	17.4	7.8
p,p'-Dichlorodiphenyltrichloroethane (DDT)	serum	ng/g of lipid	20.7	17.4	7.8
p,p'-Dichlorodiphenyldichloroethene (DDE)	serum	ng/g of lipid	18.6	8.3	7.8
Dieldrin	serum	ng/g of lipid		10.5	7.8
Endrin	serum	ng/g of lipid		5.09	7.8
Hexachlorobenzene	serum	ng/g of lipid	118	31.4	7.8
beta-Hexachlorocyclohexane	serum	ng/g of lipid	9.36	6.76	7.8
gamma-Hexachlorocyclohexane (Lindane)	serum	ng/g of lipid	14.5	10.5	7.8
Heptachlor epoxide	serum	ng/g of lipid	14.6	10.5	7.8
Mirex	serum	ng/g of lipid	14.6	10.5	7.8
trans-Nonachlor	serum	ng/g of lipid	14.5	10.5	7.8
Oxychlordane	serum	ng/g of lipid	14.5	10.5	7.8
2,4,5-Trichlorophenol	urine	µg/L	0.9	0.9	
2,4,6-Trichlorophenol	urine	µg/L	1	1.3	

Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Organophosphorus Insecticides: Dialkyl Phosphate Metabolites					
Diethylphosphate (DEP)	urine	µg/L	0.2	0.2	0.1
Dimethylphosphate (DMP)	urine	µg/L	0.58	0.5	0.5
Diethylthiophosphate (DETP)	urine	µg/L	0.09	0.1	0.2
Dimethylthiophosphate (DMTP)	urine	µg/L	0.18	0.4	0.5
Diethyldithiophosphate (DEDTP)	urine	µg/L	0.05	0.1	0.1
Dimethyldithiophosphate (DMDTP)	urine	µg/L	0.08	0.1	0.1
Organophosphorus Insecticides: Specific Insecticides and Metabolites					
3-Chloro-7-hydroxy-4-methyl-2H-chromen-2-one/ol	urine	µg/L		0.2	
2-(Diethylamino)-6-methylpyrimidin-4-ol/one	urine	µg/L		0.2	
2-Isopropyl-4-methyl-6-hydroxypyrimidine	urine	µg/L	7.2	0.7	
Malathion dicarboxylic acid	urine	µg/L	2.64		
para -Nitrophenol	urine	µg/L	0.8	0.1	
3,5,6-Trichloro-2-pyridinol	urine	µg/L	0.4	0.4	
Pyrethroid Pesticide Metabolites					
cis -3-(2,2-Dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid	urine	µg/L	0.1	0.1	
cis -3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid	urine	µg/L	0.1	0.1	
trans -3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid	urine	µg/L	0.4	0.4	
4-Fluoro-3-phenoxybenzoic acid	urine	µg/L	0.2	0.2	
3-Phenoxybenzoic acid	urine	µg/L	0.1	0.1	
Metals					
Antimony	urine	µg/L	0.04	0.04	0.07
Arsenic, Total	urine	µg/L			0.74
Arsenic (V) Acid	urine	µg/L			1.0
Arsenobetaine	urine	µg/L			0.4
Arsenocholine	urine	µg/L			0.6
Arsenous (III) Acid	urine	µg/L			1.2
Dimethylarsinic Acid	urine	µg/L			1.7
Monomethylarsonic Acid	urine	µg/L			0.9
Trimethylarsine oxide	urine	µg/L			1.0
Barium	urine	µg/L	0.12	0.12	0.31

Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Metals (continued)					
Beryllium	urine	µg/L	0.13	0.13	0.13
Cadmium	blood	µg/L	0.3	0.3	0.14
Cadmium	urine	µg/L	0.06	0.06	0.06
Cesium	urine	µg/L	0.14	0.14	0.2
Cobalt	urine	µg/L	0.07	0.07	0.08
Lead	blood	µg/dL	0.3	0.3	0.28
Lead	urine	µg/L	0.1	0.1	0.33
Mercury, Inorganic	blood	µg/L			0.42
Mercury, Total	blood	µg/L	0.14	0.14	0.2
Mercury	urine	µg/L	0.14	0.14	0.14
Molybdenum	urine	µg/L	0.8	0.8	1.5
Platinum	urine	µg/L	0.04	0.04	0.07
Thallium	urine	µg/L	0.02	0.02	0.02
Tungsten	urine	µg/L	0.04	0.04	0.04
Uranium	urine	µg/L	0.004	0.004	0.005
Perchlorate	urine	µg/L		0.05	0.05
Perfluorinated Compounds					
Perfluorobutane sulfonic acid (PFBuS)	serum	µg/L			0.4
Perfluorodecanoic acid (PFDeA)	serum	µg/L			0.3
Perfluorododecanoic acid (PFDoA)	serum	µg/L			1.0
Perfluoroheptanoic acid (PFHpA)	serum	µg/L			0.3
Perfluorohexane sulfonic acid (PFHxS)	serum	µg/L			0.3
Perfluorononanoic acid (PFNA)	serum	µg/L			0.1
Perfluorooctanoic acid (PFOA)	serum	µg/L			0.1
Perfluorooctane sulfonic acid (PFOS)	serum	µg/L			0.4
Perfluorooctane sulfonamide (PFOSA)	serum	µg/L			0.2
2-(N-Ethyl-perfluorooctane sulfonamido) acetic acid (Et-PFOSA-AcOH)	serum	µg/L			0.4
2-(N-Methyl-perfluorooctane sulfonamido) acetic acid (Me-PFOSA-AcOH)	serum	µg/L			0.6
Perfluoroundecanoic acid (PFUA)	serum	µg/L			0.3
Phthalate Metabolites					
Mono-benzyl phthalate (MBzP)	urine	µg/L	0.8	0.3	0.1
Mono-isobutyl phthalate (MiBP)	urine	µg/L		1.0	0.3
Mono-n-butyl phthalate (MnBP)	urine	µg/L	0.9	1.1	0.4
Mono-cyclohexyl phthalate (MCHP)	urine	µg/L	0.9	0.3	0.2

Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Phthalate Metabolites (continued)					
Mono-ethyl phthalate (MEP)	urine	µg/L	1.2	0.9	0.4
Mono-2-ethylhexyl phthalate (MEHP)	urine	µg/L	1.2	1.0	0.9
Mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP)	urine	µg/L		1.0	0.3
Mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP)	urine	µg/L		1.1	0.5
Mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP)	urine	µg/L			0.3
Mono-isononyl phthalate (MiNP)	urine	µg/L	0.8	0.8	1.0
Mono-methyl phthalate (MMP)	urine	µg/L		0.2	1.0
Mono-(3-carboxypropyl) phthalate (MCPP)	urine	µg/L		0.4	0.2
Mono-n-octyl phthalate (MOP)	urine	µg/L	0.9	1.0	1.0
Phytoestrogens and Metabolites					
Daidzein	urine	µg/L	0.5	1.6	1.6
O-Desmethylangolensin	urine	µg/L	0.2	0.4	0.4
Enterodiol	urine	µg/L	0.8	1.5	1.5
Enterolactone	urine	µg/L	0.6	1.9	1.9
Equol	urine	µg/L	3.0	3.3	3.3
Genistein	urine	µg/L	0.3	0.8	0.8
Polybrominated Diphenyl Ethers and Polybrominated Biphenyl					
2,2',4-Tribromodiphenyl ether (BDE 17)	serum	ng/g of lipid			1.0
2,4,4'-Tribromodiphenyl ether (BDE 28)	serum	ng/g of lipid			0.8
2,2',4,4'-Tetrabromodiphenyl ether (BDE 47)	serum	ng/g of lipid			4.2
2,3',4,4'-Tetrabromodiphenyl ether (BDE 66)	serum	ng/g of lipid			1.0
2,2',3,4,4'-Pentabromodiphenyl ether (BDE 85)	serum	ng/g of lipid			2.4
2,2',4,4',5-Pentabromodiphenyl ether (BDE 99)	serum	ng/g of lipid			5.0
2,2',4,4',6-Pentabromodiphenyl ether (BDE 100)	serum	ng/g of lipid			1.4
2,2',4,4',5,5'-Hexabromodiphenyl ether (BDE 153)	serum	ng/g of lipid			2.2
2,2',4,4',5,6'-Hexabromodiphenyl ether (BDE 154)	serum	ng/g of lipid			0.8
2,2',3,4,4',5',6-Heptabromodiphenyl ether (BDE 183)	serum	ng/g of lipid			1.7
2,2',4,4',5,5'-Hexabromobiphenyl (BB 153)	serum	ng/g of lipid			0.8
Polychlorinated Biphenyls, Non-Dioxin-Like					
2,4,4'-Trichlorobiphenyl (PCB 28)	serum	ng/g of lipid	32.4		1.7
2,2'3,5'-Tetrachlorobiphenyl (PCB 44)	serum	ng/g of lipid			0.4
2,2',4,5'-Tetrachlorobiphenyl (PCB 49)	serum	ng/g of lipid			0.4
2,2',5,5'-Tetrachlorobiphenyl (PCB 52)	serum	ng/g of lipid	12.5	12.4	0.8
2,3',4,4'-Tetrachlorobiphenyl (PCB 66)	serum	ng/g of lipid	12.4	12.4	0.8
2,4,4',5-Tetrachlorobiphenyl (PCB 74)	serum	ng/g of lipid	12.4	10.5	0.8
2,2',3,4,5'-Pentachlorobiphenyl (PCB 87)	serum	ng/g of lipid		10.5	0.4

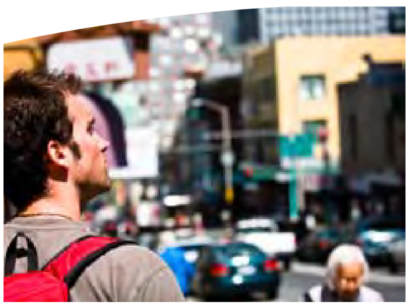
Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Polychlorinated Biphenyls, Non-Dioxin-Like (continued)					
2,2',4,4',5-Pentachlorobiphenyl (PCB 99)	serum	ng/g of lipid	12.5	10.5	0.6
2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	serum	ng/g of lipid	25.7	10.5	0.6
2,3,3',4',6-Pentachlorobiphenyl (PCB 110)	serum	ng/g of lipid		10.5	0.8
2,2',3,3',4,4'-Hexachlorobiphenyl (PCB 128)	serum	ng/g of lipid	12.4	10.5	0.4
2,2',3,4,4',5' and 2,3,3',4,4',6-Hexachlorobiphenyl (PCB 138 & 158)	serum	ng/g of lipid	41.1	10.5	0.4
2,2',3,4',5,5'-Hexachlorobiphenyl (PCB 146)	serum	ng/g of lipid	12.4	10.5	0.4
2,2',3,4',5',6-Hexachlorobiphenyl (PCB 149)	serum	ng/g of lipid		10.5	0.4
2,2',3,5,5',6-Hexachlorobiphenyl (PCB 151)	serum	ng/g of lipid		10.5	0.4
2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153)	serum	ng/g of lipid	55.6	10.5	1.1
2,2',3,3',4,4',5-Heptachlorobiphenyl (PCB 170)	serum	ng/g of lipid	17.2	10.5	0.4
2,2',3,3',4,5,5'-Heptachlorobiphenyl (PCB 172)	serum	ng/g of lipid	12.5	10.5	0.4
2,2',3,3',4,5',6'-Heptachlorobiphenyl (PCB 177)	serum	ng/g of lipid	12.5	10.5	0.4
2,2',3,3',5,5',6-Heptachlorobiphenyl (PCB 178)	serum	ng/g of lipid	12.4	10.5	0.4
2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	serum	ng/g of lipid	28.2	10.5	0.4
2,2',3,4,4',5',6-Heptachlorobiphenyl (PCB 183)	serum	ng/g of lipid	12.4	10.5	0.4
2,2',3,4',5,5',6-Heptachlorobiphenyl (PCB 187)	serum	ng/g of lipid	12.4	10.5	0.4
2,2',3,3',4,4',5,5'-Octachlorobiphenyl (PCB 194)	serum	ng/g of lipid		10.5	0.4
2,2',3,3',4,4',5,6-Octachlorobiphenyl (PCB 195)	serum	ng/g of lipid		28.1	0.7
2,2',3,3',4,4',5,6' and 2,2',3,4,4',5,5',6-Octachlorobiphenyl (PCB 196 & 203)	serum	ng/g of lipid		10.5	0.4
2,2',3,3',4,5,5',6-Octachlorobiphenyl (PCB 199)	serum	ng/g of lipid		10.5	0.4
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (PCB 206)	serum	ng/g of lipid		28.1	0.7
2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl (PCB 209)	serum	ng/g of lipid			0.7
Polychlorinated Dibenzo-*p* -dioxins, Dibenzofurans, and Dioxin-Like Polychlorinated Biphenyls					
Coplanar Polychlorinated Biphenyls					
3,4,4',5-Tetrachlorobiphenyl (PCB 81)	serum	pg/g of lipid	68.4	26.8	13.1
3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	serum	pg/g of lipid	23.2	10.8	13.9
3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	serum	pg/g of lipid	27.0	11.0	15.9
Mono-*ortho* -substituted Polychlorinated Biphenyls					
2,3,3',4,4'-Pentachlorobiphenyl (PCB 105)	serum	ng/g of lipid	12.4	10.5	0.4
2,3',4,4',5-Pentachlorobiphenyl (PCB 118)	serum	ng/g of lipid	12.5	10.5	0.6
2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156)	serum	ng/g of lipid	12.5	10.5	0.4
2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	serum	ng/g of lipid	12.5	10.5	0.4
2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	serum	ng/g of lipid	12.4	10.5	0.4
2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	serum	ng/g of lipid		10.5	0.4

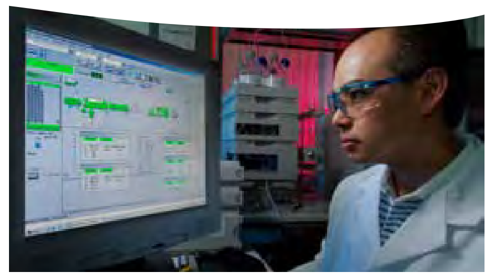
Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Polychlorinated Dibenzofurans					
1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF)	serum	pg/g of lipid	13.5	7.0	8.6
1,2,3,4,7,8,9-Heptachlorodibenzofuran (HpCDF)	serum	pg/g of lipid		7.0	8.6
1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF)	serum	pg/g of lipid	12.7	6.5	7.4
1,2,3,6,7,8-Hexachlorodibenzofuran (HxCDF)	serum	pg/g of lipid	12.6	6.1	7.9
1,2,3,7,8,9-Hexachlorodibenzofuran (HxCDF)	serum	pg/g of lipid	12.7	6.0	8.3
2,3,4,6,7,8-Hexachlorodibenzofuran (HxCDF)	serum	pg/g of lipid	12.9	5.8	8.2
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)	serum	pg/g of lipid	35.6	21.0	12.0
1,2,3,7,8-Pentachlorodibenzofuran (PeCDF)	serum	pg/g of lipid	13.2	5.8	7.1
2,3,4,7,8-Pentachlorodibenzofuran (PeCDF)	serum	pg/g of lipid	12.7	5.5	6.8
2,3,7,8-Tetrachlorodibenzofuran (TCDF)	serum	pg/g of lipid	11.9	5.2	6.0
Polychlorinated Dibenzo-*p*-dioxins					
1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin (HpCDD)	serum	pg/g of lipid	55.9	10.3	13.0
1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD)	serum	pg/g of lipid		9.0	11.9
1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin (HxCDD)	serum	pg/g of lipid	20.1	9.1	12.3
1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin (HxCDD)	serum	pg/g of lipid	20.3	9.3	12.3
1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD)	serum	pg/g of lipid	329.0	319.0	218.0
1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin (PeCDD)	serum	pg/g of lipid	14.2	6.0	4.5
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)	serum	pg/g of lipid	12.1	5.8	3.8
Polycyclic Aromatic Hydrocarbon Metabolites					
2-Hydroxyfluorene	urine	ng/L			5.0
3-Hydroxyfluorene	urine	ng/L		2.0	5.0
9-Hydroxyfluorene	urine	ng/L			5.0
1-Hydroxynaphthalene (1-Naphthol)	urine	ng/L			46.7
2-Hydroxynaphthalene (2-Naphthol)	urine	ng/L		2.4	31.1
1-Hydroxyphenanthrene	urine	ng/L		3.5	5.0
2-Hydroxyphenanthrene	urine	ng/L		3.2	5.0
3-Hydroxyphenanthrene	urine	ng/L		3.6	5.0
4-Hydroxyphenanthrene	urine	ng/L			5.0
1-Hydroxypyrene	urine	ng/L			5.0

Chemical	Matrix	Units	1999-2000	2001-2002	2003-2004
Volatile Organic Compounds (VOCs)					
Benzene	blood	ng/mL		0.024	0.024
Chlorobenzene (Monochlorobenzene)	blood	ng/mL			0.011
1,2-Dibromo-3-chloropropane (DBCP)	blood	ng/mL			0.1
Dibromomethane	blood	ng/mL			0.03
1,2-Dichlorobenzene (*o*-Dichlorobenzene)	blood	ng/mL			0.1
1,3-Dichlorobenzene (*m*-Dichlorobenzene)	blood	ng/mL			0.05
1,4-Dichlorobenzene (Paradichlorobenzene)	blood	ng/mL		0.12	0.12
1,1-Dichloroethane	blood	ng/mL			0.01
1,2-Dichloroethane (Ethylene dichloride)	blood	ng/mL			0.01
1,1-Dichloroethene (Vinylidene chloride)	blood	ng/mL			0.009
cis-1,2-Dichloroethene	blood	ng/mL			0.01
trans-1,2-Dichloroethene	blood	ng/mL			0.01
Dichloromethane (Methylene chloride)	blood	ng/mL			0.07
1,2-Dichloropropane	blood	ng/mL			0.008
2,5-Dimethylfuran	blood	ng/mL			0.012
Ethylbenzene	blood	ng/mL		0.024	0.024
Hexachloroethane	blood	ng/mL			0.011
Methyl *tert*-butyl ether (MTBE)	blood	pg/mL		0.232	2.0
Nitrobenzene	blood	ng/mL			0.3
Styrene	blood	ng/mL		0.03	0.03
1,1,2,2-Tetrachloroethane	blood	ng/mL			0.01
Tetrachloroethene (Perchloroethylene)	blood	ng/mL		0.048	0.048
Tetrachloromethane (Carbon tetrachloride)	blood	ng/mL		0.01	0.005
Toluene	blood	ng/mL		0.025	0.025
1,1,1-Trichloroethane (Methyl chloroform)	blood	ng/mL			0.048
1,1,2-Trichloroethane	blood	ng/mL			0.01
Trichloroethene (Trichloroethylene)	blood	ng/mL		0.012	0.012
o-Xylene	blood	ng/mL		0.049	0.049
m- and *p*-Xylene	blood	ng/mL		0.034	0.034

Appendix E. Abbreviations Used in Text

ACGIH	American Conference of Governmental Industrial Hygienists
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
DHHS	Department of Health and Human Services
FAO/WHO	Food and Agriculture Organization of the United Nations
FDA	Food and Drug Administration
IARC	International Agency for Research on Cancer
IOM	Institute of Medicine
IPCS	International Programme on Chemical Safety
NAS	National Academy of Sciences
NCEH	National Center of Environmental Health
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute of Occupational Safety and Health
NRC	National Research Council of the NAS
NTP	National Toxicology Program
OSHA	Occupational Safety and Health Administration
U.S.	United States
USDA	U.S. Department of Agriculture
U.S.EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WHO	World Health Organization







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