4.4 Measuring Exposure to Environmental Pollution: Indicators and Trends

Historically, human exposure to pollutants has been estimated based on:

- Measurements of ambient pollutant concentrations in air, water, or land, combined with:
- Estimates or measurements (through personal monitoring) of the frequency and duration of human contact with the contaminated media.

This approach has provided a valuable foundation for many of the regulatory and non-regulatory actions that have been taken to limit exposure to ambient pollutants. However, ambient measurements do not provide information on the degree to which ambient pollutants actually enter into the body. Another type of indicator—biomonitoring data—can help provide this information. Biomonitoring measures the amount of a pollutant in human tissue or fluids. It provides an important complement to more traditional exposure assessment indicators. National-scale biomonitoring data can be used to:

- Measure and track average body burden resulting from exposure across the entire population to a variety of pollutants.
- Enhance environmental disease prevention efforts by providing an important bridge to understanding the relationships between ambient pollutant concentrations, exposures to these pollutants, and health problems. (The lead case study, discussed earlier in Section 4.1, provides an excellent example of this application.)
- Establish reference ranges to identify people with unusually high exposures or the percentage of the population with pollutant exposures above established levels of concern (CDC, 2003a).

This section focuses primarily on biomonitoring indicators and is divided into ten parts:

- Section 4.4.1 provides background information on biomonitoring indicators—what they are and their limitations.
- Section 4.4.2 describes the major data sources for these indicators.
- Sections 4.4.3 to 4.4.8 describe specific pollutants and the data available to monitor these pollutants, including heavy metals (Section 4.4.3), cotinine (Section 4.4.4), volatile organic compounds (Section 4.4.5), pesticides (Section 4.4.6), and persistent organic pollutants (Section 4.4.7). Section 4.4.8 presents indicators that are available to specifically monitor children's exposure to some of these pollutants. In all, 10 biomonitoring indicators are currently available for tracking trends in human exposure to specific environmental pollutants. Summaries of the data linking exposure to human health effects can be found in ATSDR's toxicological profiles and EPA's criteria documents for these chemicals.
- Section 4.4.9 briefly discusses a number of pollutants—radiation, air pollutants (except for lead), biological pollutants, and disinfection by-products —for which no biomonitoring indicators currently are available or feasible. For these pollutants, traditional exposure assessment will continue to serve as the method for estimating human exposure until biomonitoring indicators become available or feasible.
- Finally, Section 4.4.10 touches on endocrine disruptors—considered an emerging issue.

4.4.1 Biomonitoring Indicators

"Dose" (the amount of a pollutant that enters the body) is often expressed as average daily dose or total potential dose. Once a pollutant crosses the boundary into the body, biological processes act on that contaminant to utilize, remove, or store the contaminant and/or its metabolites. Body burden is the concentration of a contaminant dose that is retained in the human body. Body burden can be estimated from measurements of the contaminant in the blood, urine, or adipose tissue. These measurements provide the basis for biomonitoring indicators.

The buildup of a contaminant in the body (i.e., the level of body burden) depends on a variety of factors, including the nature of the contaminant; the efficacy of the biological removal processes; and the magnitude, timing, frequency, and duration of exposure. Some contaminants, such as lead, are not easily removed and are retained in the body for long periods of time. Other contaminants, such as many volatile organic compounds (VOCs), are rapidly eliminated in exhaled breath or other removal processes.

The level of body burden is usually estimated from the concentration of a contaminant (or its metabolite) measured in the blood, urine, hair, or adipose tissue, and can be used to infer that an exposure occurred. In some cases, the level of body burden associated with a particular contaminant may prove to be an indicator of the person's extent of exposure to that pollutant.

There are a number of potential problems, however, with using body burden as an indicator of exposure. In some cases, several different pollutants may give rise to the same biomarker. Further, most measures of body burden reflect only a "snapshot" in time and many different exposure scenarios can lead to the same concentration measurement. Lastly, the measure gives no information about how the person was exposed.

Nonetheless, national scale measures of body burden are useful indicators of exposure in the population. While such measures do not necessarily provide information about the nature of the exposures, they do represent the average levels of exposure in the population as a whole. Such national scale measures of body burden are often more convenient to obtain than to estimate the exposures by accounting for all of the exposure concentrations and durations for the whole population. As mentioned earlier, body burden (biomonitoring) data are not available for all pollutants of interest to EPA. In such cases, ambient data or exposure measurements and models are used to assess human exposure.

4.4.2 Data Sources for Biomonitoring Indicators

Two primary sources provided data for the biomonitoring indicators presented in this section:

- **The National Health and Nutrition Examination Survey (NHANES)**, conducted by the National Center for Health Statistics (NCHS). Specifically, data were used from the second, third, and fourth surveys (NHANES II; NHANES III; and NHANES IV [1999-2000]).
- **EPA's National Human Exposure Assessment Survey (NHEXAS)**. Specifically, data were used from surveys of three regions: Maryland, EPA Region 5, and Arizona (NHEXAS–MD; NHEXAS–Region 5; and NHEXAS–AZ).

Two others sources of biomonitoring data—autopsy data and tissue registry data—were considered but not used for these indicators. As described below, neither of these sources contains rich biomonitoring data, which significantly limits their usefulness as data sources for human contaminant levels.

National Center for Health Statistics, National Health and Nutrition Examination Survey (NHANES)

NHANES consists of a series of surveys conducted by CDC's NCHS. The survey is designed to collect data on the health of the U.S. population, including information on topics such as nutrition, cardiovascular disease, and exposure to chemicals (CDC, 2001c). The NHANES surveys have been performed over a number of years. The first survey, NHANES I, took place from 1971 through 1975; NHANES II occurred from 1976 through 1980; NHANES III was performed from 1988 through 1994; and the most recent NHANES for which data are available took place in 1999-2000. In this section, the year(s) in which the data were collected are identified in each citation of NHANES.

As part of the survey, blood and urine samples were collected to measure the amounts of certain chemicals thought to be potentially harmful to people. Because of the extensive work involved with laboratory analysis, some chemicals were measured for all people in the survey, while other chemicals were only measured in representative subsamples of people in an age group.

The CDC National Report on Human Exposure to Environmental Chemicals (often referred to as the "CDC Report Card") (CDC, 2001c) summarizes chemical exposure data from NHANES. Information from the CDC report is presented hereafter under the heading "NHANES 1999-2000." To date, this report has been released twice. Data from the first report are updated in the larger, second report. The second report represents the U.S. population over a 2-year period, 1999-2000. Two years of data provide more stable estimates for the total population and are necessary for adequate sample sizes for some subgroup analysis. Future reports will be released every 2 years and will cover data for a 2-year period (e.g., 2001-2002, 2003-2004, 2005-2006).

National Human Exposure Assessment Survey (NHEXAS)

The goal of NHEXAS was to better understand the complete picture of human exposure to toxic chemicals by looking at humans' many exposures to all types of toxic chemicals. NHEXAS was a multiday, multimedia study that examined chemical concentrations in indoor air, outdoor air, dust, soil, food, beverages, drinking water, and tap water. For some contaminants, body burden measurements were obtained from samples of blood, hair, or urine.

Phase 1 of NHEXAS consisted of demonstration and scoping studies in Maryland; Phoenix, Arizona; and EPA Region 5 using probability-based sampling designs. Although the study was conducted in three different regions of the U.S., it was not designed to be nationally representative. The Region 5 study was conducted in Ohio, Michigan, Illinois, Indiana, Wisconsin, and Minnesota and measured metals and VOCs. The Arizona study measured metals, pesticides, and VOCs. The target population for the NHEXAS-MD study consisted of the non-institutionalized permanent residents of households in the city of Baltimore or four counties in Maryland. Samples from select environmental and biological media, as well as questionnaire data, were collected in NHEXAS-MD. The three NHEXAS studies are identified in this section as NHEXAS-AZ, NHEXAS-Region 5, or NHEXAS-MD, to indicate where they were performed.

Autopsy Data

Autopsies can provide important information about deaths resulting from known or suspected environmental or occupational hazards. For example, one of the earliest indications of the rise in lung cancer deaths came from reports that lung cancers were being identified with increasing frequency in autopsies (Hanzlick, 1998).

The value of an autopsy database for body burden and epidemiologic studies has been recognized; however, few such studies have been conducted. This is partly because autopsies are

performed on a non-random sample of deaths and because environmental contaminant levels are typically not measured during an autopsy (Moore, et al., 1996). Also, autopsies are performed on only a small percentage of the U.S. population. In 1980, autopsies were performed in approximately 17 percent of deaths in the U.S. By 1985, the percentage had declined to 14 percent. While nearly all deaths due to homicide and other medico-legal causes were autopsied, autopsies were performed in only 12 percent of all deaths due to natural causes (CDC, 1998a).

Difficulties in accessing autopsy data can limit their usefulness as well. Prior to 1995, the National Center for Health Statistics (NCHS) collected data from death certificates indicating whether an autopsy was performed. Since that time, however, such information is no longer available from the NCHS national mortality statistics databases (Hanzlick, 1998).

Tissue Registry Data

Human tissues are stored for study in many forms including solid organs, organ sections, histology slides, cells, and DNA. Tissue registries are maintained for medical education and biological research, but few studies have been conducted to identify trends in environmental contaminants in tissues using tissue registries. Tissue registry samples and information are not population-based, and at present there is no central database containing information about tissue samples (Eiseman and Haga, 1999).

EPA has conducted one of the most extensive tissue studies. From 1976 to 1987, the EPA conducted the National Human Adipose Tissue Survey (NHATS). NHATS was a national survey that collected adipose tissue samples to monitor exposure to toxic compounds among the general population. Pathologists and medical examiners from 47 metropolitan areas collected samples from autopsies and elected surgeries (Crinnion, 2000; Orban, et al., 1994). Even though the study was a significant biomonitoring effort, data from NHATS are not presented in this report because newer data sources are available.

4.4.3 What is the level of exposure to heavy metals?

Heavy metals are important environmental pollutants because they are related to several adverse health effects when ingested or inhaled. Five metals have been selected for in-depth presentation in this section: chromium, lead, arsenic, mercury, and cadmium. These metals are known to be related to severe adverse health effects and are relatively common in household, work, and school environments. Exhibit 4-32 presents EPA regulatory standards and guidelines for these five metals. Indicators are available for lead, arsenic, mercury, and cadmium and are discussed on the following pages. At present, no indicator is available for chromium, but it is discussed below because human health may be adversely affected by chromium in the environment. (For additional information on heavy metals in the environment, see Chapter 1, Cleaner Air.)

Chromium

Chromium is a naturally occurring element found in rocks, animals, plants, soil, and in volcanic dust and gases. Chromium is present in the environment in several different forms, but primarily in two valence states: trivalent chromium (III) and hexavalent chromium (VI). Chromium (III) is an essential nutrient and is much less toxic than chromium (VI), which is generally produced by industrial processes. Chromium (III) and chromium (VI) are used for chrome plating, dyes and pigments, leather tanning, and wood preserving (ATSDR, 2001).

In air, chromium compounds are present mostly as fine dust particles that eventually settle over land and water. Chromium can strongly attach to soil and only a small amount can dissolve in water and move deeper in the soil to underground water. Fish do not accumulate much chromium in their bodies from water (ATSDR, 2001).

People can be exposed to chromium by eating food containing chromium (III); breathing contaminated workplace air or experiencing skin contact during use in the workplace; drinking contaminated well water; or living near uncontrolled hazardous waste sites containing chromium or near industries that use chromium (ATSDR, 2001). Although studies have been conducted that measure the amount of chromium in drinking water, ground water, soil, and air, there are no studies that measure the body burden of chromium in human tissue.

Chromium III is an essential nutrient that helps the body use sugar, protein, and fat. An intake of 50-200 µg of chromium (III) per day is recommended for adults. On average, adults in the U.S. take in an estimated 60-80 µg of chromium per day in food. Therefore, many people's diets may not provide enough chromium (III). Without chromium III in the diet, the body loses its ability to use sugars, proteins, and fat properly, which may result in weight loss or decreased growth, improper function of the nervous system, and a diabetic-like condition. Therefore, chromium (III) compounds have been used as dietary supplements and are beneficial if taken in recommended (but not excessive) dosages (ATSDR, 2000). Chronic high exposures to chromium (III), however, may affect the skin, liver, or kidneys (ACGIH, 1991; Rom, 1992).

In general, chromium (VI) is more toxic than chromium III. Breathing in high levels (greater than 2 µg/m^3) of chromium (VI), such as in a compound known as chromic acid or chromium (VI) trioxide, can irritate the nose, causing symptoms such as runny nose, sneezing, itching, nosebleeds, ulcers, and holes in the nasal septum. These effects have primarily occurred in factory workers who make or use chromium (VI) for several months to many years. Long-term exposure to chromium (VI) has been associated with lung cancer in workers exposed to levels in air that were 100 to 1,000 times higher than those found in the natural environment. Lung cancer may occur long after exposure to chromium VI has ended (ATSDR, 2000).

No biomonitoring data are readily available for chromium. Interest is developing in examining chromium as an emerging environmental pollutant.

Exhibit 4-32: United States federal standards and criteria for five heavy metals

Heavy Metal	Drinking Water Maximum Contaminant Level (MCL)[1]	Ground Water Cleanup Level[2]	Air Standards
Lead	0.015 mg/L	0.015 mg/L	1.5 µg/L[3]
Arsenic	0.01 mg/L	0.01 mg/L	Not Applicable[4]
Mercury	0.002 mg/L	0.002 mg/L	Not Applicable[5]
Chromium	0.1 mg/L	0.1 mg/L	Not Applicable[4]
Cadmium	0.005 mg/L	0.005 mg/L	Not Applicable[4]

1. MCLs are regulatory standards developed pursuant to the Federal Safe Drinking Water Act (SDWA).
2. A groundwater cleanup level is most often the MCL (per the Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] [also known as Superfund] and Resource Conservation and Recovery Act [RCRA] guidance) for the particular contaminant. Groundwater cleanup levels are established by EPA and states on a case-by-case basis for Superfund site clean-ups and corrective actions at RCRA solid and hazardous waste management.
3. This standard is a quarterly average. Lead is a criteria air pollutant (under the Clean Air Act) and therefore has a health-based standard.
4. This heavy metal is not a criteria air pollutant and thus there is not a health-based standard. Air pollution standards for this heavy metal are technology-based standards, not health-based standards. For example, the emission standard for arsenic is that which is achievable with the best available technology (BAT) for treating arsenic air emissions. In addition, the BAT for arsenic emissions varies across industry sectors and thus emission standards for arsenic also vary across industry sectors.

Source: EPA. *Current Drinking Water Standards.* 2002; EPA. EPA. *Handbook of Groundwater Policies for RCRA Corrective Action.* 2000; EPA. *National Air Quality and Emissions Trends Report 1999.* 2001.

Indicator: Blood lead level - Category 1

Lead is a naturally occurring metal found in small amounts in rock and soil. Lead has been used industrially in the production of gasoline, ceramic products, paints, and solder. Lead-based paint and lead-contaminated dust from paint are the primary sources of lead exposure in the home. The body burden of lead can be measured as the amount of lead in blood or the amount of lead in urine. The health effects of lead are discussed in Section 4.1 of this chapter.

What the Data Show

NHANES 1999-2000. The mean blood lead levels for adults are illustrated in Exhibit 4-33. The mean blood lead level for all males in the survey was 2.0 micrograms per deciliter (µg/dL) and 1.4 µg/dL for all females. The mean blood lead level for non-Hispanic African Americans was 1.9 µg/dL. The mean blood lead level for Mexican Americans was 1.8 µg/dL (CDC, 2001c).

NHANES III (1988-1994). Blood lead levels of people were surveyed in two separate phases of NHANES III. The data collected during Phase 2 (1991 through 1994) indicated that the U.S. population's exposure to lead was decreasing.

NHEXAS-Region 5. Blood lead levels for 165 participants were obtained during NHEXAS-Region 5. Lead levels in blood were detectable for about 94 percent of the population; most of the individuals had lead levels well below 10 µg/dL. The mean blood lead level of the participants was 2.18 µg/dL (Clayton, et al., 1999).

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-33, for more information.)

Exhibit 4-33: Geometric mean and selected percentiles of total blood lead concentrations (in µg/dL) for the United States population, aged 1 year and older, by selected demographic groups, National Health and Nutrition Examination Survey (NHANES), 1999-2000

			Selected Percentiles				
	Sample Size	Geometric Mean	10th	25th	50th	75th	90th
Total, Age 1 and older	7,970	1.7	0.8	1.0	1.6	2.4	3.8
Sex							
Male	3,913	2.0	0.8	1.3	1.8	2.9	4.4
Female	4,057	1.4	0.6	0.8	1.3	1.9	3.0
Race/Ethnicity							
Black, non-Hispanic	1,842	1.9	0.7	1.1	1.7	2.8	4.2
Mexican American	2,743	1.8	0.8	1.2	1.8	2.7	4.2
White, non-Hispanic*	2,715	1.6	0.6	1.0	1.6	2.4	3.6
Age Group							
1-5 years	723	2.2	1.0**	1.4	2.2	3.3	4.8**
6-11 years	905	1.5	0.7	0.9	1.3	2.0	3.3
12-19 years	2,135	1.1	0.4	0.8	1.0	1.4	2.3
20 years and older	4,207	1.8	0.7	1.0	1.7	2.5	3.9

* Includes other racial/ethnic groups.

Source: CDC. *Second National Report on Human Exposure to Environmental Chemicals.* 2003.

Indicator

Urine arsenic level - Category 2

Arsenic occurs in rock, soil, water, air, plants, and animals. Exposure occurs when arsenic is further released into the environment through erosion, volcanic action, forest fires, or human actions. Human activities involve its use in wood preservatives, dyes, paints, paper production, and cement manufacturing. Arsenic mining is also a source of human exposure (EPA, 2001a).

Inorganic arsenic has been recognized as a human poison since ancient times, and large oral doses (above 60,000 ppb in food or water) can produce death. Lower levels of inorganic arsenic (ranging from about 300 to 30,000 ppb in food, water, or pharmaceuticals) may cause symptoms such as stomach ache, nausea, vomiting, and diarrhea. Inorganic arsenic is a multi-site human carcinogen. Populations with exposures above several hundred ppb are reported to have increased risks of skin, bladder, and lung cancer. The U.S. Department of Health and Human Services (USDHHS) has determined that inorganic arsenic is a known carcinogen. The International Agency for Research on Cancer (IARC) had determined that inorganic arsenic is carcinogenic to humans. Both the EPA and the National Toxicology Program (NTP) have classified inorganic arsenic as a known human carcinogen (ATSDR, 2001).

A large number of adverse noncarcinogenic effects have been reported in humans. The most prominent are changes in the skin, (e.g., hyperpigmentation and keratoses). Other effects that have been reported include alterations in gastrointestinal, cardiovascular, hematological, pulmonary, neurological, immunological, and reproductive developmental function (NRC, 1999).

Children who are exposed to arsenic may have many of the same effects as adults, including irritation of the stomach and intestines, blood vessel damage, skin changes, and reduced nerve function. Thus, all health effects observed in adults are of potential concern in children (ATSDR, 2001).

What the Data Show

NHEXAS-Region 5. Arsenic levels in urine were measured for approximately 202 participants during NHEXAS-Region 5. The mean urine arsenic level was 29.32 micrograms per liter (µg/L), while the median urine arsenic level was 3.65 µg/L. The mean level is much higher than the median level, indicating that the distribution is highly skewed to the higher values (Clayton, et al., 1999).

NHANES. Future NHANES studies will include arsenic. Therefore, NHANES will serve as the biomonitoring data source for arsenic. When NHANES becomes the indicator data source for arsenic, the indicator will become a Category 1 indicator.

Data Source

NHEXAS, Environmental Protection Agency. (See Appendix B, page B-33, for more information.)

Indicator: Blood mercury level - Category I

Mercury is a naturally occurring metal that is widespread and persistent in the environment. It is found in elemental form and in various organic compounds and complexes. Methylmercury (one organic form of mercury) can accumulate up the food chain in aquatic systems and lead to high concentrations of methylmercury in predatory fish. Consumption of contaminated fish is the major source of human exposure to methylmercury in the U.S. (NRC, 2000).

Methylmercury is rapidly absorbed from the gastrointestinal tract and readily enters the brain, where it accumulates and is slowly converted to inorganic mercury. A spectrum of adverse health effects has been observed following methylmercury exposure, with the severity depending largely on the magnitude of the dose. The most severe effects reported in humans were seen following high-dose poisoning episodes in Japan and Iraq. The fetus is considered much more sensitive than the adult. Prenatal exposures interfere with the growth and migration of neurons and have the potential to cause irreversible damage to the developing central nervous system. Infants exposed in utero during the Japan and Iraqi episodes were born with severe disabilities, such as mental retardation, seizure disorders, cerebral palsy, blindness, and deafness. Chronic low-dose prenatal methylmercury exposure from maternal consumption of fish has been associated with more subtle end points of neurotoxicity (e.g., IQ deficits, abnormal muscle tone, decrements in motor function, attention and visuospatial performance) (NRC, 2000).

The human health effects of mercury are diverse and depend upon the forms of mercury encountered and the severity and length of exposure. Large acute exposures to elemental mercury vapor can result in lung damage. Lower dose or chronic inhalation may affect the nervous system, resulting in symptoms such as weakness, fatigue, weight loss, gastrointestinal problems, and behavioral and personality changes. Organic mercury is more toxic than inorganic and elemental mercury (CDC, 2001c). Health effects of organic mercury include vision changes, sensory changes in the limbs, cognitive disturbances, dermatitis, and muscle deterioration. The developing nervous system of the fetus and infants is susceptible to the effects of methylmercury (CDC, 2003).

What the Data Show

NHANES 1999-2000. The blood mercury level reported in NHANES is total blood mercury, including both organic and inorganic mercury. Mercury levels were measured in blood and urine during NHANES 1999-2000 for 705 children aged 1-5 years, and 1,709 adult females aged 16-49. The mean blood mercury level for males and females aged 1-5 years was 0.34 micrograms per liter (µg/L), and the mean blood mercury level for adult females was 1.02 µg/L.

NHEXAS-Region 5. Mercury concentrations in human hair were measured for 182 participants during NHEXAS-Region 5. The mean mercury level in hair, annualized for seasonality, was 287 ppb. More people in older age categories have high levels of mercury in their hair. This increase in mercury level was found not to be an effect of income level (Pellizari, et al., 1999).

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-33, for more information.)

Exhibit 4-34: Geometric mean and selected percentiles of blood mercury concentrations (in µg/L) for males and females aged 1-5 years and females aged 16 to 49 years in the U.S. population, National Health and Nutrition Examination Survey (NHANES), 1999-2000

			Selected Percentiles				
	Sample Size	Geometric Mean	10th	25th	50th	75th	90th
Age Group and Sex							
Males/Females 1-5 years	705	0.3	<LOD	<LOD	0.3	0.5	1.4
Males	387	0.3	<LOD	<LOD	0.2	0.5	1.1
Females	318	0.3	<LOD	<LOD	0.2	0.8	1.6
Females 16-49 years	1709	1.0	0.2	0.4	0.9	2.0	4.9
Race/Ethnicity (females 16-49 only)							
Mexican Americans	579	0.8	0.2	0.4	0.9	1.4	2.6
Non-Hispanic blacks	370	1.4	0.3	0.6	1.3	2.6	4.8
Non-Hispanic whites	588	0.9	<LOD	0.4	0.9	1.9	5.0

<LOD means less than the limit of detection, which is 0.14 µg/L.

Source: CDC. *Second National Report on Human Exposure to Environmental Chemicals*. 2002.

Indicator

Blood cadmium level - Category 1

Elemental cadmium is a metal that is usually found in nature combined with other elements such as oxygen, chlorine, or sulfur. Cadmium enters the environment from the weathering of rocks and minerals that contain cadmium. Exposure to cadmium can occur in occupations such as mining or electroplating, where cadmium is used or produced. Cadmium exposure can also occur from exposure to cigarette smoke (CDC, 2001c).

Cadmium and its compounds are toxic. Once absorbed into the human body, cadmium can remain for decades. Exposure to cadmium for many years may result in cadmium accumulation in the kidneys and serious kidney damage. Chronic ingestion of cadmium has resulted in osteomalacia, a bone disorder similar to rickets. Acute airborne exposure, as occurs from welding on cadmium-alloy metals, can result in swelling (edema) and scarring (fibrosis) of the lungs (CDC, 2003).

What the Data Show

NHANES 1999-2000. This survey measured blood cadmium levels in people 1 year and older, and urine cadmium levels in a sample of people 6 years and older. Recent advances in analytical chemistry have made it possible to measure cadmium in very small amounts in blood and urine. Finding a measurable amount of cadmium in the blood or urine does not mean that the level of cadmium causes an adverse health effect (CDC, 2001c). The blood cadmium biomonitoring measurements are similar among males and females as well as among the racial or ethnic groups sampled. Exhibit 4-35 shows that blood levels were higher among people 20 years of age or older than for people younger than 20 years of age (CDC, 2001c). The mean urine cadmium level was 0.3 µg/L (CDC, 2001c).

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-34, for more information.)

Exhibit 4-35: Geometric mean and selected percentiles of blood cadmium concentrations (in µg/L) for the United States population, aged 1 year and older, by selected demographic groups, National Health and Nutrition Examination Survey (NHANES), 1999-2000

			Selected Percentiles				
	Sample Size	Geometric Mean	10th	25th	50th	75th	90th
Total, Age 1 and Older	7,970	0.4	<LOD	<LOD	0.3	0.6	1.0
Sex							
Male	3,913	0.4	<LOD	<LOD	0.4	0.6	1.0
Female	4,057	0.4	<LOD	<LOD	0.3	0.6	1.0
Race/Ethnicity							
Black, non-Hispanic	1,842	0.4	<LOD	<LOD	0.3	0.6	1.0
Mexican American	2,743	0.4	<LOD	<LOD	0.4	0.4	0.7
White, non-Hispanic*	2,715	0.4	<LOD	<LOD	0.4	0.5	1.0
Age Group							
1-5 years	723	**	<LOD	<LOD	<LOD	0.3	0.4
6-11 years	905	**	<LOD	<LOD	<LOD	0.3	0.4
12-19 years	2,135	0.3	<LOD	<LOD	0.3	0.3	0.8
20+ years	4,207	0.5	<LOD	<LOD	0.4	0.6	1.0

* Includes other racial/ethnic groups. <LOD= Less than the limit of detection of the analytical method.

Source: CDC. *Second National Report on Human Exposure to Environmental Chemicals.* 2003.

4.4.4 What is the level of exposure to cotinine?

Environmental tobacco smoke (ETS) is a dynamic, complex mixture of more than 4,000 chemicals found in both vapor and particle phases. Many of these chemicals are known toxic or carcinogenic agents (ALA, et al., 1994). The EPA has classified ETS as a known human carcinogen and estimates that it is responsible for approximately 3,000 lung cancer deaths per year among non-smokers in the U.S. (EPA, NCEA, December 1992).

Cotinine is a major metabolic product of nicotine and is currently regarded as the best biomarker for exposure of active smokers and non-smokers to ETS. Measuring cotinine is preferred over measuring nicotine because, although both are specific for exposure to tobacco, cotinine remains in the body much longer than nicotine.

Indicator: Blood cotinine level - Category I

Cotinine can be measured in blood, urine, saliva, and hair. Non-smokers exposed to ETS have cotinine levels of less than 1 nanogram per milliliter (ng/mL), with heavy exposure to ETS producing levels in the 1 to 15 ng/mL range. Active smokers almost always have levels higher than 15 ng/mL (CDC, 2001c).

What the Data Show

NHANES 1999-2000. Exhibit 4-36 presents data for the U.S. non-smoking population aged 3 years and older. Males have higher levels than females, and people aged 20 years and older have lower levels than those younger than 20 years of age. Levels for non-Hispanic African Americans are higher than for other ethnic groups (CDC, 2001c).

NHANES III (1988-1991). As part of NHANES III, CDC determined that the median level of cotinine among non-smokers in the U.S. was 0.20 ng/mL (Pirkle, et al., 1996, in CDC, 2001c). Results from NHANES 1999-2000 show that the median cotinine level has decreased to less than 0.050 ng/mL—more than a 75 percent decrease from NHANES III to NHANES 1999-2000 (CDC, 2001c). NHANES III (1988-1991) provided the first evidence from a national study that serum cotinine levels are higher among Black smokers than among White or Mexican American smokers at all levels of cigarette smoking (Caraballo, et al., 1998).

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-34, for more information.)

Exhibit 4-36: Selected percentiles of serum cotinine concentrations (in ng/mL) for the United States non-smoking population, aged 3 years and older, National Health and Nutrition Examination Survey (NHANES), 1999-2000

	Sample Size	Selected Percentiles				
		10th	25th	50th	75th	90th
Total, Age 3 years and Older	5,999	<LOD	<LOD	0.06	0.24	1.02
Sex						
Male	2,789	<LOD	<LOD	0.08	0.30	1.20
Female	3,210	<LOD	<LOD	<LOD	0.18	0.85
Race/Ethnicity						
Black, non-Hispanic*	1,333	<LOD	<LOD	0.13	0.50	1.43
Mexican American	2,242	<LOD	<LOD	<LOD	0.14	0.51
White, non-Hispanic**	1,949	<LOD	<LOD	0.05	0.21	0.95
Age Group						
3-11 years	1,174	<LOD	<LOD	0.11	0.50	1.88
12-19 years	1,773	<LOD	<LOD	0.11	0.54	1.65
20+ years	3,052	<LOD	<LOD	<LOD	0.17	0.63

* Research in progress to determine whether levels for black, non-Hispanic people may be affected by biological factors.
** Includes other racial/ethnic groups.
<LOD= Less than the limit of detection of 0.05 ng/mL in serum.

Source: CDC. *Second National Report on Human Exposure to Environmental Chemicals.* 2003.

4.4.5 What is the level of exposure to volatile organic compounds?

In addition to the health effects attributed to VOCs themselves, VOCs are also chemical compounds that contribute significantly to the formation of ground-level ozone (smog) when released to the air. Exposure to ground-level ozone can damage lung tissue and cause serious respiratory illness. (For additional information on VOCs in the environment, see Chapter 1, Cleaner Air.)

Indicator: Blood VOC levels - Category I

Biomonitoring data for volatile compounds are difficult to obtain because these compounds do not persist for very long in the body. For this reason, biomonitoring data are indicative of recent exposure only. Only relatively older sources of data, NHEXAS and NHANES III, are available for the body burden of VOCs.

What the Data Show

NHEXAS-Region 5. Blood levels of four VOCs were obtained for participants in NHEXAS-Region 5. The four compounds were benzene, chloroform, tetrachloroethylene (PERC), and trichloroethylene (TCE). The mean level of benzene measured in blood was 0.07 µg/L. The mean level of chloroform was 0.07 µ/L. The mean level of PERC was 0.21 µg/L. The mean level of TCE was below the limit of detection (Clayton, et al., 1999).

NHANES III (1988-1994). Blood samples were analyzed for the presence of VOCs during NHANES III. NHANES III was conducted on a nationwide probability sample of approximately 33,994 persons aged 2 months or older. Of these, an exposure questionnaire was administered and blood samples analyzed for VOCs in a convenience sample of 1,018 adult participants aged 20 to 59 years. Toluene, styrene, and benzene were present in the blood of more than 75 percent of the participants. Analysis of this and other data collected during NHANES III shows a strong association between lifetime cigarette smoking and toluene, benzene, and styrene levels (Churchill and Kaye, 2001).

Data Source

NHANES III (1988-1994), National Center for Health Statistics. (See Appendix B, page B-34, for more information.)

4.4.6 What is the level of exposure to pesticides?

Organophosphate pesticides account for about half of the insecticides used in the U.S. Organophosphate pesticides are active against a broad spectrum of insects and are used on food crops as well as in residential and commercial buildings and on ornamental plants and lawns. Exposure to these pesticides occurs primarily from ingestion of food products or from residential use (CDC, 2001c).

The mechanism of toxicity of the organophosphate pesticides is to inhibit the enzyme that breaks down acetylcholine, which transfers nerve impulses between nerve cells or from a nerve cell to other types of cells, such as muscle cells. This leads to a buildup of acetylcholine, which overstimulates muscles, causing symptoms such as weakness and paralysis (CDC, 2001c). (For additional information on pesticides in the environment, see Chapter 1, Cleaner Air; Chapter 2, Purer Water; and Chapter 3, Better Protected Land.)

Indicator: Urine organophosphate levels to indicate pesticides - Category 1

Pesticides biomonitoring data are obtained by measuring the chemicals that pesticides are broken down into in the body. Measurement of these pesticide metabolites reflects exposure to pesticides that has occurred predominantly in the last few days (CDC, 2001c). The reason is that these metabolites persist within the body for only a short time.

Presently, national biomonitoring data are available primarily for organophosphate pesticides. Future studies may provide additional indicators for non-organophosphate pesticides, such as carbamates and persistent pesticides.

What the Data Show

NHANES 1999-2000. Urine levels of organophosphate pesticide metabolites were measured in a subsample of NHANES participants 6 through 59 years of age who were selected to be representative of the U.S. population. Finding a measurable amount of one or more metabolites in urine does not mean that the level of the organophosphate causes an adverse health effect. Whether organophosphate pesticides at the levels of metabolites reported during NHANES 1999-2000 are a cause for health concern is not known (CDC, 2001c). Exhibit 4-37 shows the amount of each metabolite in urine reported in NHANES 1999-2000.

NHEXAS-MD. Urine levels of metabolites of some common pesticides were measured during NHEXAS-MD. 1-naphthol (1NAP) is a urinary metabolite of both carbaryl and naphthalene. The mean urine level of 1NAP measured for 338 participants was 33.7 µg/L. 3,5,6-trichloro-2-pyridinol (TCPY) is the major metabolite in urine of the pesticides chlorpyrifos, chlorpyrifos-methyl, and triclopyr. The mean urine level of TCPY measured for 346 participants was 6.8 µg/L. Malathion dicarboxylic acid (MDA) is a principal metabolite of malathion, an organophosphate pesticide used against insects. The mean urine level for MDA measured during NHEXAS-MD was below the level of detection. Atrazine mercapturate (AM) is a urinary metabolite of atrazine, a widely used herbicide in the U.S. The mean urine level for AM measured during NHEXAS-MD was below the level of detection (MacIntosh, et al., 1999).

Exhibit 4-37: Geometric mean and selected percentiles of selected pesticide metabolite urine concentrations and creatinine-adjusted levels for the United States population aged 6-59 years, National Health and Nutrition Examination Survey (NHANES), 1999-2000

	Sample Size	Geometric Mean	Selected Percentiles (95% confidence interval) 10th	25th	50th	75th	90th
Dimethylphosphate							
µg/L of urine	1,949	NC	< LOD	< LOD	0.74	2.80	7.90
µg/g of creatinine*	1,949	NC	< LOD	< LOD	0.81	2.93	8.46
Dimethylthiophosphate							
µg/L of urine	1,948	1.82	< LOD	< LOD	2.70	10.0	38.0
µg/g of creatinine*	1,948	1.64	< LOD	< LOD	2.12	9.57	32.0
Dimethyldithiophosphate							
µg/L of urine	1,949	NC	< LOD	< LOD	< LOD	2.30	12.0
µg/g of creatinine*	1,949	NC	< LOD	< LOD	< LOD	1.86	10.1
Diethylphosphate							
µg/L of urine	1,949	1.03	< LOD	< LOD	1.20	3.10	7.50
µg/g of creatinine*	1,949	0.92	< LOD	< LOD	0.93	2.73	7.94
Diethylthiophosphate							
µg/L of urine	1,949	NC	< LOD	< LOD	0.49	0.76	1.3
µg/g of creatinine*	1,949	NC	< LOD	< LOD	0.25	0.71	1.7
Diethyldithiophosphate							
µg/L of urine	1,949	NC	< LOD	< LOD	0.08	0.20	0.47
µg/g of creatinine*	1,949	NC	< LOD	< LOD	0.07	0.20	0.55

µg per gram of creatinine in urine.
<LOD= Less than the limit of detection for the analytical method.

NC=Not calculated - Proportion of results below limit of detection was too high to provide a valid result.

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-35, for more information.)

4.4.7 What is the level of exposure to persistent organic pollutants?

Persistent organic pollutants (POPs) are manmade organic chemicals that remain in the environment for long periods of time. Some POPs are toxic; others are not. Toxic POPs are of a special concern because they often remain toxic for decades or longer. The more persistent a toxic chemical is, the greater the probability for human exposure over time.

POPs have been linked to adverse health effects such as cancer, nervous system damage, reproductive disorders, and disruption of the immune system in both human and animals. POPs released in one part of the world can travel to regions far from their place of origin, because they circulate globally long after their release into the atmosphere, oceans, and other pathways (EPA, 2001b).

Under the United Nations Environment Program, the international community has identified 12 chemicals as primary POPs. These chemicals include certain insecticides such as dichlorodiphenyl-trichloroethane (DDT) and chlordane, which were once commonly used to control pests, and polychlorinated biphenyls (PCBs), which were used in hundreds of commercial applications for electrical, heat transfer, and hydraulic equipment, and in plasticizers in paints, plastics, and rubber products.

The 12 chemicals targeted by EPA as POPs are the pesticides aldrin, chlordane, DDT, mirex, toxaphene, dieldrin, endrin, and heptachlor; hexachlorobenzene, an industrial chemical; PCBs; polychlorinated dibenzo-p-dioxins (dioxins); and polychlorinated dibenzo-p-furans (furans) (EPA, 2001b).

The following discussion of human exposure to POPs is derived from the *Second National Report on Human Exposure to Environmental Chemicals*, published in January 2003 by the CDC National Center for Environmental Health (CDC, 2003). Four of the 12 POPs are not addressed by the CDC report and are therefore not addressed specifically in this chapter. These four chemicals are aldrin, toxaphene, dieldrin, and endrin. The remaining POPs were not evaluated for indicators at this time but EPA anticipates that these chemicals will become indicators in the future.

Chlordane and Heptachlor

In 1988, EPA banned the use and production of chlordane in the U.S. Chlordane is an organochlorine pesticide that was applied in and around buildings to eliminate termites and was also used as an agricultural and lawn pesticide. The technical grade of chlordane consists of a group of related chemicals, including heptachlor, *cis*-chlordane, *trans*-chlordane, and *trans*-nonachlor. Note that heptachlor was also used individually as a pesticide separate from chlordane. However, pesticide applications were mostly made with technical grade chlordane and therefore chlordane is the main form of heptachlor exposure.

Within the body, chlordane is metabolized to oxychlordane and heptachlor is metabolized to heptachlor epoxide. Human exposure to chlordane and heptachlor is determined by measuring the blood serum concentrations of oxychlordane, *trans*-nonachlor, and heptachlor epoxide. However, generally recognized guidelines for serum levels of these metabolites have not been established.

The NHANES 1999-2000 mean levels of oxychlordane and heptachlor epoxide in the overall population were below the lipid-adjusted level of detection, which averaged 7.4 ng/g of lipid. The NHANES II (1976-1980) 95th percentile level was about twice the NHANES 1999-2000 level for oxychlordane and *trans*-nonachlor.

DDT

DDT was initially used by the military during the 1940s to control mosquitoes that carried vector-borne diseases such as malaria. EPA banned the use of DDT in the U.S. in 1973. DDT, however, is still produced and used in other countries.

For the general population, food is the most common pathway of exposure. Diets that involve large amounts of Great Lakes fish will increase an individual's exposure to DDT. Food intake of DDT has decreased since the 1950s; however, food imported to the U.S. may have DDT contamination, especially food imported from tropical regions where DDT is used in the greatest quantities.

Dichlorodiphenyldichloroethylene (DDE) (more persistent than DDT) is a major DDT metabolite that can be produced in people or in the environment. DDT in the human body reflects either a relatively recent exposure or a cumulative past exposure over time. A high DDT-to-DDE ratio may indicate a recent exposure, and a low DDT-to-DDE ratio may indicate an exposure in the more distant past.

The NHANES 1999-2000 95th percentile levels (lipid-adjusted serum) for DDT and DDE in the overall population range from 5-fold to 15-fold lower than levels detected in a non-random subsample of NHANES II (1976-1980). These decreases in the U.S. levels are consistent with the decreased use and manufacture of these chemicals. Also, within NHANES 1999-2000, the group aged 12 to 19 years had DDE levels 2-fold lower than the group 20 years and older.

Hexachlorobenzene (HCB)

Hexachlorobenzene is a persistent, bioaccumulative, and toxic pollutant (EPA, 2003b). It was commonly used as a pesticide until 1965, as a fungicide to protect wheat seeds, and for a variety of industrial purposes, including rubber, aluminum, and dye production and wood preservation (EPA, 2003c). In 1984, EPA canceled its registered use. There currently are no commercial uses of HCB in the U.S. (EPA,

2003c); however, HCB is still formed as a by-product during the manufacture of other chemicals (mainly solvents) and pesticides.

Human exposure to HCB can occur through work in or proximity to chemical manufacturing sites where it is formed as a by-product or to waste facilities where it is disposed. People also can be exposed by consuming foods tainted with hexachlorobenzene (EPA, 2003c). EPA has set the maximum contaminant level (MCL) for hexachlorobenzene in drinking water at 1 part per billion. If HCB levels exceed this level, the water supplier must notify the public (EPA, 2002g).

HCB has been found to potentially cause skin lesions and nerve and liver damage when people are exposed at levels above the MCL for relatively short periods (EPA, 2002g). Lifetime exposure at levels above the MCL can damage the liver and kidneys and cause reproductive effects, benign tumors of endocrine glands, and cancer (EPA, 2002g).

Epidemiologic studies of persons orally exposed to HCB have not shown an increased cancer incidence. However, EPA has classified HCB as a probable human carcinogen (Group B2) based on animal studies that have reported cancer of the liver, thyroid, and kidney from oral HCB exposure. Very few inhalation data are available (EPA, 2003c).

Generally recognized guidelines for HCB serum levels are not available. HCB was detected in 0.6 percent of people during the 1999-2000 NHANES study. Finding detectable amounts does not mean that those levels produce adverse health effects. HCB has a residence time of approximately 15 years in body fat.

PCBs

PCBs are chlorinated aromatic hydrocarbon chemicals that were once used as electrical insulating and heat exchange fluids. Within the U.S., peak production occurred in the early 1970s and production within the U.S. was banned in 1979. Concern over these chemicals remains high because they are still released into the environment.

Sources of exposure for the general population include release of PCBs from waste sites and from fires involving transformers and capacitors; ingestion of foods containing PCBs due to contamination of animal feeds; migration from packaging materials; and accumulation in the fatty tissues of livestock. PCBs are found at higher concentrations in fatty foods. In occupational settings, workers can be exposed to PCBs from remediation activities at hazardous waste sites and from the repair of transformers, capacitors, and hydraulic systems (CDC, 2003a).

The Food and Drug Administration and the Occupational Safety and Health Administration have developed criteria for allowable levels of PCBs in foods and the workplace. EPA has established criteria for water and for the storage and removal of PCB-contaminated wastes.

Overall, there are three categories of at least 25 different PCB compounds (termed congeners) as determined by molecular structure. Congeners are closely related chemical compounds. The three categories are coplanar PCBs, mono-ortho substituted PCBs, and other PCBs. The significance of these categories is that coplanar and mono-ortho substituted PCBs have health effects similar to dioxins. Overall, the human health effects of PCBs include liver disorders, elevated lipids, and gastrointestinal cancers (CDC, 2003a).

The detection of serum PCBs can reflect either recent or past exposures to PCBs. Those PCBs with higher degrees of chlorination persist in the human body from several months to years after exposure. In the NHANES 1999-2000 subsample, the frequency of detection of the eight mono-ortho substituted PCBs ranged from 2 percent to 47 percent. Finding detectable amounts does not mean that those levels result in adverse health effects. (For additional information on PCBs in the environment, see Chapter 2, Purer Water; Chapter 3, Better Protected Land; and Chapter 5, Ecological Condition.)

Polychlorinated Dibenzo-p-Dioxins (Dioxins) and Polychlorinated Dibenzo-p-Furans (Furans)

Dioxins and furans are similar classes of chlorinated aromatic chemicals usually generated as pollutants or by-products. They have no commercial or natural use. Processes that result in their generation include the incineration of waste, the production of pulp and paper, and the synthesis of various manmade chemicals. Releases from industrial sources have decreased by approximately 80 percent since the 1980s. The largest releases of dioxins and furans today are the open burning of household and municipal trash, landfill fires, and agricultural and forest fires. In the environment, dioxins and furans occur as a mixture of about 20 congeners (i.e., closely related chemical compounds).

Human exposure occurs primarily through foods that are contaminated with dioxins and furans. Food contamination occurs due to the accumulation of these chemicals in the food chain and in high-fat foods, such as dairy products, eggs, animal fats, and some types of fish. People have also been exposed through industrial accidents, the burning of PCBs, and through the spraying of contaminated herbicides such as Agent Orange. Workplace exposures are rare and generally recognized standards for external exposure have not been established.

Human health effects associated with dioxins and furans are wide-ranging. Given that the exposure of the general population occurs as exposure to a mixture of congeners, the effects of individual congeners are difficult to determine. Overall, associated dioxin and

furan health effects include liver disorders, fetal injury, porphyria, elevated lipid levels, chloracne, hormonal changes, neurologic damage, and immunogic changes. The dioxin cogener termed TCDD is the most toxic form of dioxin and it is classified as a known human carcinogen.

It is estimated that human serum lipid-based levels of overall dioxins and furans have decreased by 80 percent since the 1980s and the low NHANES 1999-2000 values support that estimation. The levels detected via NHANES 1999-2000 are far below those associated with occupational and unintentional exposures that resulted in human health effects.

Further, the NHANES 1999-2000 subsample reveals that the more highly chlorinated dioxin and furan cogeners are the main contributors to the human body burden. The higher concentrations in human tissues of these cogeners are due to their greater presence in the food chain, resistance to metabolic breakdown, and greater solubility in body fat. Half-lives for all the dioxin and furan cogeners range from 3 to 19 years and TCDD is estimated to be 7 years.

4.4.8 What are the trends in exposure to environmental pollutants for children?

Children may be affected by environmental pollutants quite differently than adults, both because children may be more highly exposed to pollutants and because they may be more vulnerable to the toxic effects of pollutants. Children generally eat more food, drink more water, and breathe more air relative to their size than do adults, and consequently may be exposed to relatively higher amounts of pollutants. Also, unlike adults, children's normal activities, such as putting their hands in their months or playing on the ground, create greater opportunities for exposures to pollutants. In addition, environmental pollutants may affect children disproportionately because their organ systems are still developing and therefore may be more susceptible (EPA, December 2000). This section presents three environmental pollutants that represent exposures of concern to children: lead, mercury, and cotinine.

Indicator: Blood lead level in children - Category 1

Infants, children, and fetuses are more vulnerable to the effects of lead because the blood-brain barrier is not fully developed (Nadakavukaren, 2000). Thus, a smaller amount of lead will have a greater effect in children than in adults. In addition, ingested lead is more readily absorbed into a child's bloodstream. Children absorb 40 percent of ingested lead into the bloodstream, while adults absorb only 10 percent. Because of lead's adverse effects on cognitive development, CDC has defined an elevated blood lead level as equal to or greater than 10 µg/dL for children under 6 years of age (CDC, 2001c).

What the Data Show

In NHANES III (1988-1994), the mean blood lead levels for children ages 1 to 5 declined from 3.6 µg/dL in Phase 1 (1988 to 1991) to 2.7 µg/dL in Phase 2 (1991 to 1994). Over the same time interval, the percentage of children aged 1 to 5 years with elevated blood lead levels decreased from 8.6 percent to 4.4 percent (Pirkle, 1998). In NHANES 1999-2000, the geometric median blood lead level for children 1 to 5 years old is 2.2 µg/dL. The median blood lead level for children 6 to 11 years old is 1.5 µg/dL (see exhibit 4-8 in this chapter).

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-35, for more information.)

Indicator: Blood mercury level in children - Category I

Children may be more highly exposed to mercury and may be more vulnerable to its toxic effects. The health effects of mercury are diverse and can include developmental and neurological effects in children.

What the Data Show

Extremely limited information has been available about children's exposure to mercury and how it relates to levels in adults. Exhibit 4-38 shows that the geometric mean of blood mercury levels among U.S. children measured in NHANES 1999-2000 was 0.34 µg/L. The geometric mean of blood mercury levels of women of childbearing age was 1.02 µg/L. Levels among women of childbearing age are particularly important because they reflect levels of mercury to which the fetus is exposed (NRC, 2000). During a toxicological review of mercury levels, the National Research Council estimated a benchmark dose, which was an estimate of a methylmercury exposure to the fetus, associated with an increase in abnormal scores on cognitive function tests among children. The lower 95 percent confidence bound on the benchmark dose was 58 µg/L (NRC, 2000). To account for uncertainties in exposure measures and variability in individual response to toxic effects of mercury, the NRC recommended an uncertainty factor of 10 to calculate a reference dose. EPA published its final reference dose of 5.8 µg/L, agreeing with NRC. Ninety percent of children 1 to 5 years old and women of childbearing age are below this level (CDC, 2001c).

Exhibit 4-38: Geometric mean and selected percentiles of total blood mercury concentrations (in µg/L) for United States children aged 1-5 years, and women aged 16-49 years, National Health and Nutrition Examination Survey (NHANES), 1999-2000

			Selected Percentiles				
	Sample Size	Geometric Mean	10th	25th	50th	75th	90th
Children, aged 1-5 years, males and females	705	0.34	<LOD	<LOD	0.30	0.50	1.40
Females, 16-49 years	1,709	1.02	0.20	0.40	0.90	2.00	4.90

<LOD = below the limit of detection of the analytical method of 0.14 µg/dL blood.
Source: CDC. *Second National Report on Human Exposure to Environmental Chemicals.* 2003.

Data Source

NHANES III (1999), National Center for Health Statistics. (See Appendix B, page B-35, for more information.)

Indicator: Blood cotinine level in children - Category I

Children are at particular risk from ETS, which may exacerbate asthma among susceptible children and also greatly increase the risk for lower respiratory-tract illness, such as bronchitis and pneumonia, among young children (CDC, 2001c). NHANES 1999-2000 data show that people younger than 20 years have higher cotinine levels than people 20 years and older (CDC, 2003). (See Exhibit 4-35 located in Section 4.4.4.) Blood cotinine level is an indicator of exposure to ETS. During NHANES 1999-2000, the average blood cotinine level for children aged 3 to 11 years was 0.11 ng/mL. This level was the same for children in the 12 to 19 years subgroup (CDC, 2003).

For the general population, as part of NHANES III (1988-1991), CDC determined that the median serum level (50th percentile) of cotinine among non-smokers in the U.S. was 0.20 ng/mL. As determined during NHANES 1999-2000, the median cotinine level decreased to 0.059 ng/mL, a 70 percent decrease. This reduction suggest a marketed decrease in exposure of the general U.S. population to ETS since the 1988-1991 period. Further, compared with the results for the 1988-1991 period, NHANES 1999-2000 reveals that cotinine levels declined in each of the population groups defined by age, sex, and race/ethnicity (CDC, 2003).

Data Source

NHANES 1999-2000, National Center for Health Statistics. (See Appendix B, page B-36, for more information.)

4.4.9 Pollutants for Which Biomonitoring Data Are Not Available

As mentioned above, biomonitoring is an emerging field. More biomonitoring indicators are available now than a few years ago. Still, there are many environmental pollutants for which biomonitoring techniques are not available or feasible. These include radiation, air pollutants (except for lead), biological pollutants, and disinfection by-products. Biomonitoring efforts have begun recently for disinfection by-products; however, at this time data are not sufficient to develop indicators for these pollutants. All these pollutants are of concern because exposure is widespread. For these pollutants, exposure assessments currently rely primarily on ambient data.

What is the level of exposure to radiation?

Radiation is energy given off by atoms in the form of particles or electromagnetic rays. There are actually many different types of electromagnetic radiation that have a range of energy levels. They form the electromagnetic spectrum and include radio and micro waves, heat, light, and x-rays (EPA, 2002w).

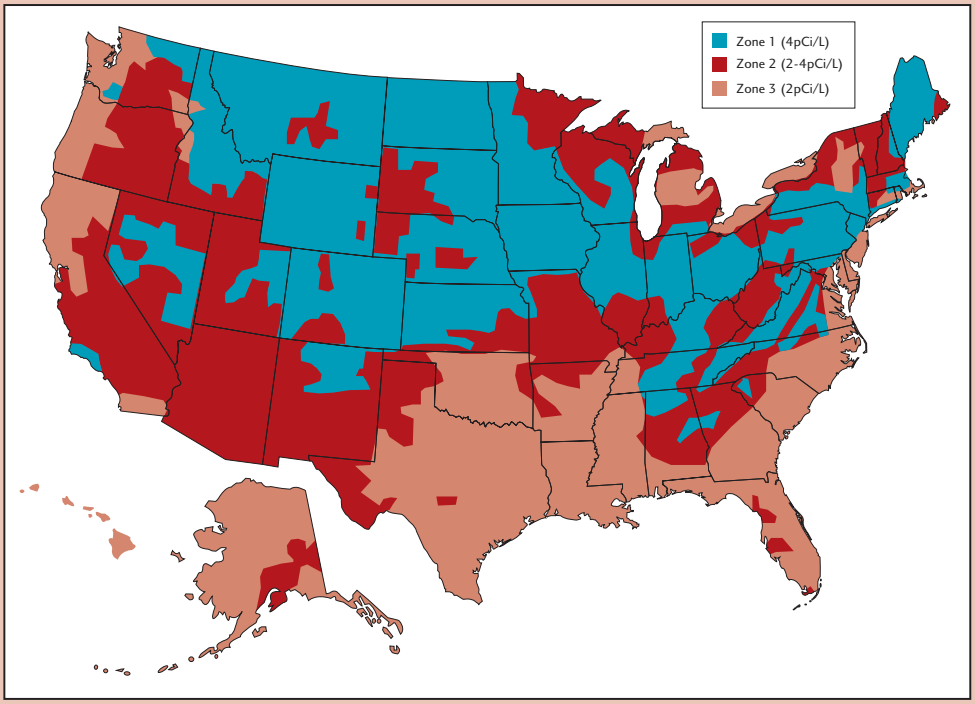
Radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to change them chemically, is referred to as "non-ionizing radiation." Examples of this kind of radiation are sound waves, visible light, and microwaves (EPA, 2002y). Non-ionizing radiation can be used for some common tasks, such as using microwave radiation for telecommunications and heating food, infrared radiation for producing warmth, and radio waves for broadcasting (EPA, 2002y). Non-ionizing radiation has relatively long wavelengths and low frequencies, in the range of 1 million to 10 billion Hertz (EPA, 2002y).

Radiation that has enough energy to actually break chemical bonds or strip electrons away from atoms is called "ionizing radiation (EPA, 2002x)." Radioactive materials that decay spontaneously produce ionizing radiation. Any living tissue in the human body can be damaged by ionizing radiation. The body attempts to repair the damage, but sometimes the damage is too severe or widespread, or mistakes are made in the natural repair process. The most common forms of ionizing radiation are alpha and beta particles, or gamma and X-rays (EPA, 2002x). Ionizing radiation has very short wavelengths, and very high frequencies, in the range of 100 billion billion Hertz (EPA, 2002y). This is the type of radiation that people usually think of as 'radiation.' Ionizing radiation can be used to generate electric power, to kill cancer cells, and in many manufacturing processes (EPA, 2002y).

Radiation can affect the body in a number of ways, and the adverse health consequences of exposure may not be seen for many years. These adverse health effects can range from mild effects, such as skin reddening, to serious effects such as cancer and death, depending on the amount of radiation absorbed by the body (the dose), the type of radiation, the route of exposure, and the length of time a person is exposed. Exposure to very large doses of radiation may cause death within a few days or months. Exposure to lower doses of radiation may lead to an increased risk of developing cancer or other adverse health effects (CDC, 2003).

There are three basic pathways for radiation exposure. These are inhalation, ingestion, and direct exposure. Each of the different routes, or pathways, by which people can be exposed to radiation result in exposure to different parts of the body (EPA, 2002z). Exposure by the inhalation

Exhibit 4-39: EPA map of radon zones in the United States



Source: Modified from EPA, Office of Air and Radiation. EPA Map of Radon Zones. April 2003. (May 2, 2003; *http://www.epa.gov/iaq/radon/zonemap.html*).

pathway occurs when people breathe radioactive materials into the lungs. The chief concerns are radioactively contaminated dust, smoke, or gaseous radionuclides such as radon (EPA, 2002z). Radon is a colorless, tasteless, and odorless gas that comes from the decay of uranium found in nearly all soils. Levels of radon vary throughout the country. Radon usually moves upward from the ground and migrates into homes and other buildings through cracks and other holes in their foundations. The buildings trap radon inside, where it accumulates and may become a health hazard if the building is not properly ventilated (EPA, June 2000; EPA, 2002b).

No biomonitoring data are feasible for national estimates of exposure to radon. Data for average national indoor and outdoor radon levels are available, but unlike biomonitoring data, these data do not represent the amount of radon found in human tissue. Rather, they are the levels of radon measured in the air. Radon levels vary throughout the U.S. Exhibit 4-39 shows the distribution of radon levels throughout the country (EPA, 2003d). Based on a national residential radon survey completed in 1991, the average indoor radon level is 1.3 picocuries per liter in the U.S. The average outdoor level is about 0.4 picocuries per liter (EPA, 2002b).

Radiation exposure by the ingestion pathway occurs when someone swallows radioactive materials. For example, exposure by ingestion can occur when drinking water becomes radioactively contaminated, or when food is grown in contaminated soil. Alpha and beta emitting radionuclides are of most concern for ingested radioactive materials. They release large amounts of energy directly to tissue, causing DNA and other cell damage (EPA, 2002z).

The third pathway of concern is direct or external exposure from radioactive material. The concern about exposure to different kinds of radiation varies by the particular type of particle or wave that is being emitted. Alpha particles cannot penetrate the outer layer of skin, but open wounds may pose a risk. Beta particles can burn the skin in some cases, or damage eyes. Greatest concern is about gamma radiation. Different radionuclides emit gamma rays of different strength, but gamma rays can travel long distances and penetrate entirely through the body. Gamma rays can be slowed by dense material (shielding), such as lead, and can be stopped if the material is thick enough. Examples of shielding are containers; protective clothing, such as a lead apron; and soil covering buried radioactive materials (EPA, 2002z).

Radiation can occur from man-made sources such as x-ray machines; or from natural sources such as the sun and outer space, and from some radioactive materials such as uranium in soil (CDC, 2003). About 80 percent of human exposure to radiation is from naturally occurring forms of radiation. The remaining 20 percent of exposure is to manmade radiation sources, primarily medical x-rays (CDC, 2003).

Radiation doses that people receive are measured in units called "rem (CDC, 2003)." Most people receive about 300 mrem every year from natural background sources of radiation, primarily radon. Health physicists generally agree on limiting a person's exposure beyond background radiation to about 100 millirem (mrem) per year from all sources. Exceptions are occupational, medical or accidental exposures. (Medical X-rays generally deliver less than 10 mrem). EPA and other regulatory agencies generally limit exposures from specific sources to the public to levels well under 100 mrem. This is far below the exposure levels that cause acute health effects (EPA, 2002x).

For additional information on radiation in the environment, see Chapter 1, Cleaner Air.

What is the level of exposure to air pollutants?

Criteria air pollutants are common air pollutants comprised of ozone, nitrogen dioxide, carbon monoxide, sulfur dioxide, lead, and particulate matter. The health effects associated with criteria air pollutants are discussed in Chapter 1, Cleaner Air, Section 1.1.3. Ozone is the result of a chemical reaction in the atmosphere between VOCs and nitrogen oxides. Nitrogen dioxide comes from the burning of gasoline, natural gas, coal, and oil. Cars are an important source of nitrogen dioxide.

Carbon monoxide comes from the burning of gasoline, natural gas, coal, and oil. Carbon monoxide reduces the ability of blood to bring oxygen to body cells and tissues. Carbon monoxide may be particularly hazardous to people who have heart or circulatory problems.

Particulate matter (PM) can be emitted directly into the atmosphere, such as dust from roads or elemental carbon (soot) from wood combustion. PM can also be formed in the atmosphere from primary gaseous emissions such as sulfur dioxide and nitrogen oxides, which come from power plants, industrial facilities, automobiles, and other types of combustion sources.

The primary source of sulfur dioxide is the burning of coal and oil, especially high-sulfur coal from the eastern U.S., and industrial processes (paper, metals). The primary source of lead in ambient air was leaded gasoline, which has been phased out in the U.S. Other sources of lead include paint, smelters, and the manufacture of lead storage batteries. Major health effects associated with lead are discussed in Section 4.1.

Except for lead, biomonitoring methods are not available or feasible for the remaining criteria air pollutants. Data for average national ambient air pollutant levels are available (see Chapter 1, Cleaner Air). Research on actual intake measures of air pollutants and their relationship to ambient levels as measured by monitoring networks is under way. Many other studies have found links between air

pollutants and disease, as noted in the discussion of diseases and their relationships to environmental pollutants (see Section 4.1).

What is the level of exposure to biological pollutants?

Biological pollutants are or were living organisms. In addition to arthropod-borne, foodborne, or waterborne disease discussed previously, other biological agents can promote poor indoor air quality and may be a major cause of days lost from work or school and of doctor and hospital visits. Some can even damage surfaces inside and outside the residence. Some common indoor biological pollutants include: animal dander (minute scales from hair, feathers, or skin); dust mite and cockroach parts, fungi (molds); infectious agents (bacteria or viruses); and pollen.

Everyone is exposed to biological pollutants. The effects on one's health, however, depend upon the type and amount of biological pollution and the individual person. Some people do not experience health reactions from certain biological pollutants, while others may experience one or more of the following reactions: allergic, infectious, or toxic.

Except for the spread of infections indoors, allergic reactions may be the most common health problem with indoor air quality in homes. They are often connected with animal dander (mostly from cats and dogs), with house dust mites (microscopic animals living in household dust), and with pollen. Allergic reactions can range from mildly uncomfortable to life-threatening, as in a severe asthma attack. Health experts are especially concerned about people with asthma, who have very sensitive airways that can react to various irritants, making breathing difficult. Infectious diseases caused by bacteria and viruses, such as flu, measles, chicken pox, and tuberculosis, may be spread indoors. Most infectious diseases pass from person to person through physical contact. Crowded conditions with poor air circulation can promote this spread. Some bacteria and viruses thrive in buildings and circulate through indoor ventilation systems. (For additional information on indoor air pollution, see Chapter 1, Cleaner Air.)

As with air pollutants and radiation, biomonitoring methods are not available or feasible for many of the biological pollutants discussed in this section.

What is the level of exposure to disinfection by-products?

Disinfection by-products (DBPs) are chemicals that form in drinking water when disinfectants are added during the drinking water treatment process. Disinfectants are added to drinking water to kill bacteria and other microbes that cause disease. DBPs are formed when the disinfectants react with organic matter (primarily from leaf and vegetation decay) that is found naturally in drinking water sources such as rivers and lakes (EPA, 2002c). The most common drinking water disinfectant is chlorine. Other lesser-used disinfectants include chloramines, chlorine dioxide, ozone, and ultraviolet light. More than 200 million people within the U.S. drink disinfected water (EPA, June 2001a).

Hundreds of different DBPs—most of which result from chlorine—have been identified in drinking water, and occurrence data have been reasonably established for over 30 DBPs (EPA, ORD, November 1997). The two types of DBPs that are typically measured by drinking water utilities are trihalomethanes (THMs) and haloacetic acids (HAs).

DBP levels vary throughout the country because the levels are dependent on several factors, including amount of organic matter in the drinking water source, amount of rainfall in the area, season of the year, water temperature, type of disinfectant used, water treatment plant configuration, and size of the water system distribution system (EPA, 1999).

Current information on DBP exposures draws on monitoring results from drinking water systems. Data for average national levels of THMs in treated drinking water are available. Water monitoring for DBPs is of limited value in classifying or identifying individual exposures to DBPs. Individual exposures are influenced by route of exposure (ingestion, inhalation, dermal absorption), individual habits relating to water use or consumption, time and spatial distribution of DBPs in the water system, and seasonal variables that affect the precursors to DBPs (e.g., rainfall, temperature). The complex nature of exposure to DBPs will require a better understanding of the chain of events as illustrated in Exhibit 4-1.

4.4.10 Endocrine Disruptors—An Emerging Issue

An endocrine disruptor is defined as an exogenous agent that alters the function of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny or (sub)populations (IPCS, 2002). A number of pharmaceuticals, pesticides, commercial chemicals and environmental contaminants are known to disrupt the endocrine system across a wide range of species—invertebrates, fish, birds, reptiles, and mammals.

There is little information on the magnitude and pattern of human exposures to endocrine disruptors. The limited exposure data that exist are primarily for various environmental media, such as chemical concentrations in air, food, and water. Often these data are limited by geographical regions and cannot be extrapolated to national trends. More relevant measures of human exposure, such as chemical concentrations in human blood, breast milk, and human tissue, are rare. Often these data are available only for high exposure areas and populations. As chemicals suspected of contributing to endocrine disruption in humans are identified, it will be necessary to obtain high-quality exposure data to perform human risk assessments. Each major state of the science report on endocrine disruptors has acknowledged the critical need for research to increase our understanding of human exposures and related health outcomes.

The human health issue regarding exposure to endocrine disruptors primarily relates to: (1) adverse effects observed in fish and wildlife, (2) the increased incidence of specific endocrine-related adverse human health outcomes/diseases, and (3) observations of endocrine disruption in well-conducted experiments involving laboratory animals. These chemicals can affect the endocrine system in several ways including interfering with hormone synthesis and release from the endocrine gland, competing with the hormone for the binding sites on transport proteins in the blood, binding to the receptor to either block hormone action or mimic it, and producing changes in hormone metabolism and elimination (IPCS, 2002).

There are a few clear examples of adverse human health effects following high exposures to environmental chemicals (e.g., accidental releases or poisoning incidents). Analysis of the human data by itself has not provided firm evidence of direct causal associations between low level exposure to endocrine-disrupting chemicals and adverse human health outcomes.

Of particular interest is exposure during very early development, both *in utero* and postnatally. Sexual differentiation, growth, and development are under hormonal control. Many of these early processes are unique to this time period and disruptions of carefully timed processes may lead to irreversible adverse human health outcomes. Interest has focused on: (1) adverse effects on reproductive and sexual development and function, (2) altered immune system, nervous system, and thyroid development and function, and (3) cancers of various endocrine-sensitive tissues including the testes, breast, and prostate. Additional research is needed to determine whether linkages exist between these adverse human health outcomes/diseases and exposure to suspected endocrine disruptors. However, this research is challenging as the manifestation of the condition is frequently not observed until years after exposure has occurred and the measured concentration of the chemicals in the affected adult may be very different from in utero, neonatal, or pre-pubertal exposures/concentrations that may have given rise to the adverse outcome.

4.5 Assessing the Environmental Burden of Disease

Many factors may cause or influence disease in humans. These factors include heredity, social factors, dietary factors, and environmental factors (e.g., chemical pollutants, infectious microorganisms, and radiation). The extent to which environmental factors influence overall disease is not entirely understood. Disease burden, global burden of disease, and environmental burden of disease are concepts used to express the burden of disease on society:

- **Disease burden** is the effect on society of both disease-related mortality and disease-related morbidity (Kay, 2000; WHO, 2002). It is assessed by several health measures, including mortality rates, morbidity rates, and the number of days in the hospital. Historically, disease burden has been investigated by analyzing disease outcomes, such as cancer, rather than analyzing risk factors that may cause cancer or disease in general. For example, it is easier to compare cancer incidence between two countries than to compare risk factors of cancer; ionizing radiation may be the major risk factor for cancer in country A, while dioxin may be the major risk factor in country B.
- **Global burden of disease (GBD)** assesses the disease burden on a worldwide basis and then apportions that burden to various causes, such as genetic, behavioral, and environmental.
- **Environmental burden of disease (EBD)** measures that portion of the GBD which is due solely to environmental risk factors.

EBD provides a method for summarizing the environmental health of populations. The summary health data collected from EBD measurements help identify environmental risk factors with significant public health implications. EBD data can also be used to help prioritize funding allocations for health and environmental research, assist in environmental policy development, justify environmental advocacy, assess the cost-effectiveness of interventions, and monitor the progress of a population's health (Prüss, et al., 2001). More important, EBD provides a way to normalize risk factors, allowing comparable health evaluations between populations. Two approaches are commonly used to determine the degree of disease burden that stems from environmental risk factors:

- The **outcome-based approach** determines the degree to which specific environmental risk factors cause a disease relative to other environmental risk factors.