# Results by Chemical Group

## Metals

# Antimony

CAS No. 7440-36-0

## General Information

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

Antimony enters the environment from natural sources and from its use in industry. People are exposed to antimony primarily from food and to a lesser extent from air and drinking water. Workplace exposures occur as a result of breathing the air near industries such as 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 than for trivalent compounds (Elinder and Friberg, 1986). An elimination half-life of about 95 hours has been estimated after occupational exposures (Kentner et al., 1995).

Inorganic antimony salts irritate the mucous membranes, skin, and eyes. Acute inhalational exposure to antimony has been associated with irritation of the respiratory tract

## Table 3. Antimony

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.132** (.120-.145) | **.130** (.120-.140) | **.210** (.200-.230) | **.330** (.300-.350) | **.420** (.390-.460) | 2276 |
| | 01-02 | **.134** (.126-.142) | **.130** (.120-.130) | **.180** (.180-.190) | **.260** (.240-.300) | **.340** (.320-.390) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.176** (.154-.200) | **.190** (.160-.200) | **.260** (.230-.280) | **.350** (.300-.390) | **.400** (.320-.600) | 316 |
| | 01-02 | **.146** (.134-.160) | **.150** (.130-.160) | **.200** (.180-.210) | **.260** (.230-.310) | **.330** (.280-.380) | 368 |
| 12-19 years | 99-00 | **.158** (.141-.178) | **.170** (.150-.180) | **.230** (.210-.270) | **.340** (.290-.420) | **.460** (.350-.510) | 663 |
| | 01-02 | **.169** (.156-.184) | **.150** (.140-.180) | **.230** (.220-.250) | **.350** (.320-.400) | **.460** (.360-.480) | 762 |
| 20 years and older | 99-00 | **.123** (.112-.137) | **.110** (.100-.120) | **.190** (.180-.220) | **.310** (.280-.330) | **.420** (.390-.470) | 1297 |
| | 01-02 | **.128** (.119-.136) | **.120** (.120-.130) | **.170** (.160-.190) | **.240** (.220-.280) | **.330** (.280-.380) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.143** (.131-.157) | **.140** (.130-.150) | **.240** (.220-.250) | **.350** (.320-.370) | **.470** (.390-.570) | 1132 |
| | 01-02 | **.145** (.136-.154) | **.130** (.130-.150) | **.200** (.180-.200) | **.310** (.280-.330) | **.390** (.350-.430) | 1335 |
| Females | 99-00 | **.122** (.109-.137) | **.120** (.100-.130) | **.190** (.180-.220) | **.300** (.270-.330) | **.390** (.350-.460) | 1144 |
| | 01-02 | **.125** (.117-.133) | **.110** (.110-.120) | **.180** (.160-.190) | **.240** (.210-.260) | **.310** (.260-.350) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.132** (.108-.161) | **.130** (.110-.160) | **.200** (.180-.240) | **.300** (.250-.370) | **.410** (.330-.560) | 787 |
| | 01-02 | **.142** (.130-.154) | **.120** (.110-.130) | **.200** (.160-.220) | **.250** (.230-.300) | **.360** (.300-.390) | 683 |
| Non-Hispanic blacks | 99-00 | **.175** (.148-.207) | **.180** (.150-.200) | **.260** (.220-.290) | **.390** (.310-.470) | **.490** (.400-.620) | 554 |
| | 01-02 | **.180** (.164-.197) | **.160** (.150-.180) | **.250** (.210-.280) | **.350** (.320-.410) | **.450** (.370-.530) | 667 |
| Non-Hispanic whites | 99-00 | **.128** (.115-.144) | **.120** (.110-.140) | **.210** (.180-.220) | **.320** (.280-.350) | **.400** (.350-.500) | 768 |
| | 01-02 | **.126** (.117-.135) | **.120** (.120-.130) | **.180** (.170-.180) | **.240** (.220-.270) | **.340** (.310-.390) | 1132 |

and impaired pulmonary function (Renes, 1953). Pulmonary edema may occur in severe cases (Cordasco et al., 1973). Dysrhythmias and T-wave changes on electrocardiogram have also been noted in people after both therapeutic (Berman, 1988; Ming-Hsin et al., 1958) and occupational exposures (Briegner et al., 1954). Ingestion of antimony may cause people to experience a metallic taste, and gastrointestinal symptoms such as vomiting, diarrhea, abdominal pain, and ulcers (Werrin, 1962). The toxicity of stibine after acute inhalational exposure has been reported to be similar to that of arsine, resulting in hemolysis with abdominal and back pain (Dernehl et al., 1944).

Workplace standards for air exposure to antimony have been established by OSHA and ACGIH. Antimony trioxide is rated as being possibly carcinogenic to humans by IARC. Information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA's IRIS Web site at http://www.epa.gov/iris and from ATSDR's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

**Interpreting Levels of Urinary Antimony Reported in the Tables**

Urinary antimony levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range to be a representative sample of the U.S. population. Previous studies reporting measurements in general populations (Minoia et al., 1990; Paschal et al., 1998) or compiled reference ranges (Hamilton et al., 1994) have found values slightly higher than those reported here, which may be due to methodologic, population, or exposure differences. Several investigations of airborne exposures to antimony in workers show urinary levels that are many times higher than those seen in this *Report*, even when exposure levels were below workplace air standards (Iavicoli et al., 2002; Kentner et al., 1995; Ludersdorf et al., 1987; Bailly et al., 1991).

## Table 4. Antimony (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.124** (.108-.143) | **.119** (.102-.143) | **.185** (.163-.213) | **.274** (.233-.333) | **.382** (.333-.430) | 2276 |
| | 01-02 | **.126** (.119-.134) | **.120** (.115-.126) | **.173** (.162-.188) | **.265** (.242-.296) | **.364** (.320-.414) | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.191** (.147-.248) | **.183** (.156-.220) | **.250** (.196-.414) | **.439** (.271-.741) | **.537** (.333-1.30) | 316 |
| | 01-02 | **.178** (.159-.200) | **.173** (.150-.193) | **.228** (.200-.272) | **.338** (.265-.480) | **.469** (.313-.727) | 368 |
| 12-19 years | 99-00 | **.121** (.104-.140) | **.119** (.095-.146) | **.176** (.146-.206) | **.259** (.206-.310) | **.310** (.228-.421) | 663 |
| | 01-02 | **.121** (.112-.131) | **.115** (.106-.127) | **.159** (.138-.186) | **.224** (.199-.245) | **.266** (.244-.310) | 762 |
| 20 years and older | 99-00 | **.118** (.104-.135) | **.111** (.096-.136) | **.174** (.149-.209) | **.263** (.227-.320) | **.352** (.320-.391) | 1297 |
| | 01-02 | **.122** (.115-.129) | **.115** (.108-.121) | **.167** (.153-.179) | **.265** (.241-.296) | **.364** (.318-.405) | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.112** (.099-.127) | **.108** (.095-.127) | **.164** (.146-.181) | **.226** (.204-.268) | **.319** (.235-.391) | 1132 |
| | 01-02 | **.114** (.107-.123) | **.108** (.103-.115) | **.153** (.138-.171) | **.228** (.205-.250) | **.333** (.272-.421) | 1334 |
| Females | 99-00 | **.137** (.117-.161) | **.131** (.108-.164) | **.212** (.176-.247) | **.318** (.257-.400) | **.425** (.357-.485) | 1144 |
| | 01-02 | **.139** (.131-.148) | **.132** (.124-.140) | **.196** (.178-.211) | **.295** (.267-.317) | **.371** (.333-.444) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.120** (.107-.135) | **.114** (.105-.129) | **.167** (.148-.203) | **.249** (.207-.313) | **.333** (.280-.357) | 787 |
| | 01-02 | **.138** (.128-.149) | **.129** (.117-.143) | **.182** (.159-.203) | **.269** (.229-.308) | **.338** (.308-.429) | 682 |
| Non-Hispanic blacks | 99-00 | **.114** (.099-.133) | **.112** (.098-.130) | **.163** (.144-.183) | **.236** (.195-.338) | **.339** (.255-.425) | 554 |
| | 01-02 | **.123** (.113-.134) | **.115** (.106-.126) | **.163** (.150-.181) | **.232** (.208-.267) | **.300** (.248-.373) | 667 |
| Non-Hispanic whites | 99-00 | **.129** (.109-.152) | **.124** (.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 |

**Comparing Adjusted Geometric Means**

Geometric mean levels of urinary antimony for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). In NHANES 2001-2002, adjusted geometric mean levels of urinary antimony were slightly higher for the group aged 6-11 years than for either groups aged 12-19 years or 20 years and older. The group aged 12-19 years had higher levels than the group aged 20 years and older. Mexican Americans had slightly higher levels than non-Hispanic whites. It is unknown whether these differences associated with age or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of antimony in urine does not mean that the level of antimony causes an adverse health effect. Whether antimony at the levels reported here is a cause for health concern is not yet known; more research is needed. These urine antimony data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of antimony than are found in the general population. These data will also help scientists plan and conduct research about exposure to antimony and health effects.

# Figure 1. Antimony (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
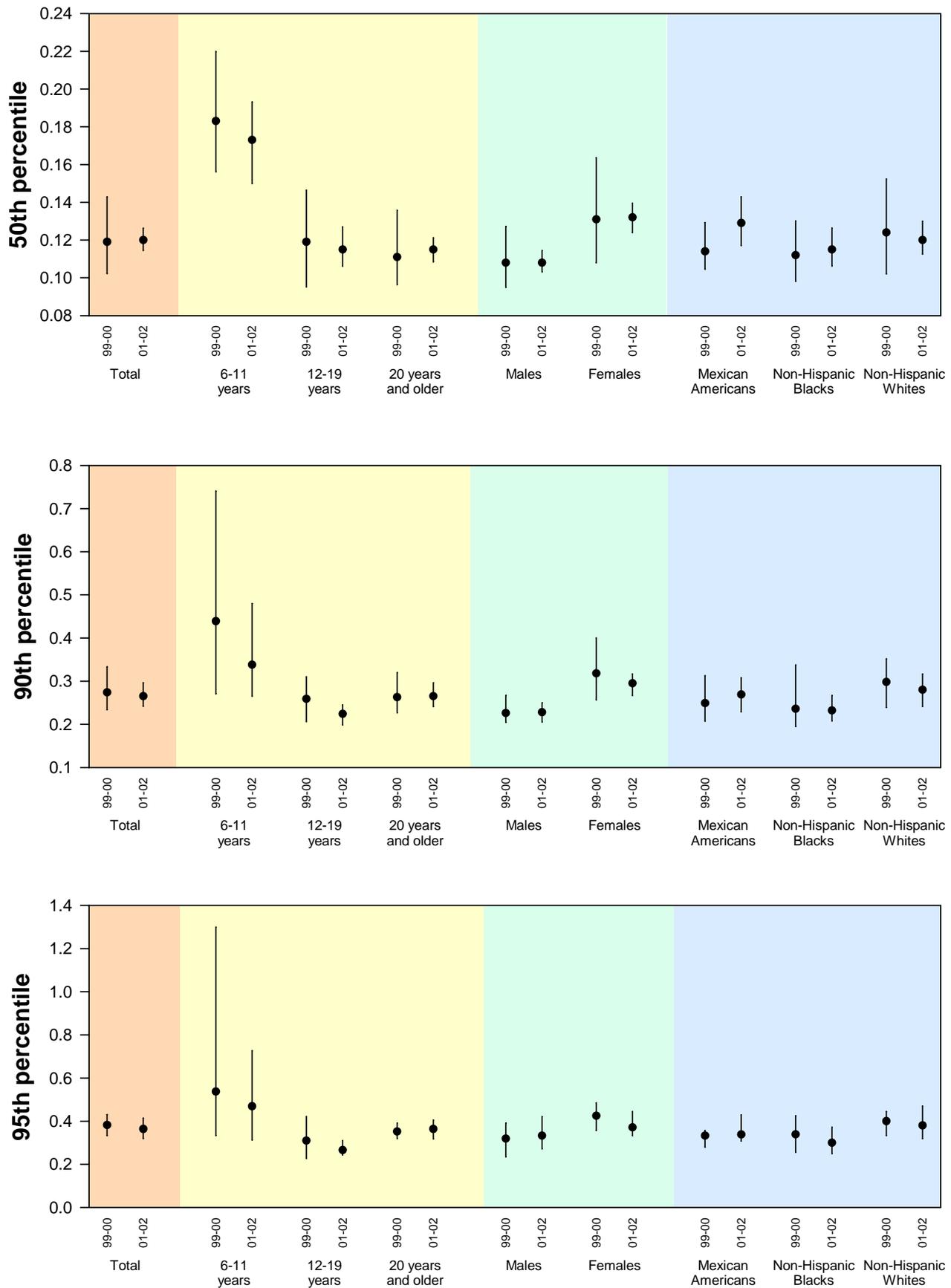
# Barium

CAS No. 7440-39-3

**General Information**

Elemental barium is a silver-white metal. Barium's abundance in the earth's crust is approximately 0.05%. In nature, it combines with other chemicals such as sulfur or carbon and oxygen to form numerous barium salts. Of the various salts, approximately half are freely soluble in water, whereas the others are practically insoluble (notably barium sulfate and barium carbonate). Barium compounds are used by the oil and gas industries to make drilling muds. These compounds are also produced commercially for use 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 are available for sale as rodenticides.

People can be exposed to barium in air, water, and food.

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 are exposed to barium dust. Certain foods, such as brazil nuts, are exceptionally high in barium (Genter, 2001).

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 occurs after intentional or accidental ingestion of barium carbonate in rodenticides (Genter, 2001). Barium blocks cellular efflux of potassium resulting in extracellular profound hypokalemia. Symptoms include perioral paresthesias, vomiting, diarrhea, weakness, paralysis, hypertension, and cardiac dysrhythmias. The lethal dose of barium by ingestion is reported to be between 0.8-0.9 grams (Jourdan et al., 2001).

## Table 5. Barium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **1.50** (1.35-1.66) | **1.50** (1.30-1.70) | **3.00** (2.70-3.40) | **5.40** (4.60-6.10) | **6.80** (6.20-8.40) | 2180 |
| | 01-02 | **1.52** (1.41-1.65) | **1.63** (1.50-1.75) | **3.12** (2.76-3.51) | **5.22** (4.73-5.74) | **7.48** (6.54-8.12) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **2.15** (1.70-2.72) | **2.20** (1.80-2.30) | **3.90** (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) | **2.08** (1.74-2.49) | **3.62** (2.86-4.39) | **5.37** (4.26-7.38) | **6.88** (5.37-8.49) | 368 |
| 12-19 years | 99-00 | **1.97** (1.78-2.19) | **2.00** (1.60-2.30) | **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) | **4.09** (3.48-4.72) | **6.69** (5.55-7.87) | **9.00** (7.25-11.4) | 762 |
| 20 years and older | 99-00 | **1.36** (1.24-1.51) | **1.40** (1.30-1.70) | **2.70** (2.50-3.00) | **5.00** (4.20-5.50) | **6.40** (5.70-8.30) | 1262 |
| | 01-02 | **1.43** (1.32-1.54) | **1.50** (1.39-1.65) | **2.85** (2.55-3.26) | **4.86** (4.53-5.47) | **7.14** (6.08-8.12) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **1.70** (1.54-1.88) | **1.80** (1.70-2.00) | **3.10** (2.80-3.40) | **5.50** (4.20-6.30) | **7.50** (5.90-9.40) | 1083 |
| | 01-02 | **1.64** (1.47-1.82) | **1.80** (1.63-1.98) | **3.15** (2.76-3.73) | **5.52** (4.82-6.35) | **7.87** (6.49-9.32) | 1335 |
| Females | 99-00 | **1.33** (1.15-1.53) | **1.50** (1.20-1.60) | **2.80** (2.30-3.10) | **5.10** (4.20-5.90) | **6.80** (5.60-10.4) | 1097 |
| | 01-02 | **1.43** (1.30-1.56) | **1.43** (1.28-1.63) | **3.10** (2.73-3.43) | **4.86** (4.44-5.88) | **7.15** (6.32-7.86) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **1.35** (1.25-1.46) | **1.30** (1.20-1.50) | **2.60** (2.30-2.90) | **4.50** (4.00-5.10) | **6.30** (5.50-6.80) | 692 |
| | 01-02 | **1.21** (1.06-1.37) | **1.24** (1.08-1.45) | **2.55** (2.04-2.90) | **4.31** (3.65-5.49) | **6.08** (5.21-8.22) | 683 |
| Non-Hispanic blacks | 99-00 | **1.34** (1.12-1.62) | **1.30** (1.20-1.50) | **2.50** (2.20-2.80) | **5.10** (3.70-6.40) | **7.40** (5.40-13.9) | 540 |
| | 01-02 | **1.30** (1.14-1.48) | **1.41** (1.22-1.62) | **2.61** (2.31-2.82) | **4.28** (3.70-5.18) | **5.99** (4.87-7.26) | 667 |
| Non-Hispanic whites | 99-00 | **1.56** (1.36-1.80) | **1.70** (1.60-2.00) | **3.30** (2.80-3.70) | **5.40** (4.50-6.20) | **7.20** (6.20-8.80) | 765 |
| | 01-02 | **1.61** (1.46-1.77) | **1.67** (1.53-1.82) | **3.30** (2.86-3.73) | **5.66** (4.94-6.30) | **7.70** (6.61-8.49) | 1132 |

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 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). 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. Barium is not rated for carcinogenicity. Information about external exposure and health effects is available from the U.S. EPA's IRIS Web site at http://www.epa.gov/iris and from ATSDR's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

### Interpreting Levels of Urinary Barium Reported in the Tables

Urinary barium levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range

to be a representative sample of the U.S. population. Previous studies reporting urinary levels of barium in general populations have found values generally similar to those documented in this *Report* (Minoia et al., 1990; Paschal et al., 1998). In addition, levels determined in clinically submitted specimens are broadly comparable (Komaromy-Hiller et al., 2000). Median urinary levels of barium found in welders of barium-containing electrodes were 60 times higher than the median levels in this *Report* (Zschiesche et al., 1992) without obvious adverse effects. Urinary concentrations in acute poisonings are often hundreds to thousands times higher.

### Comparing Adjusted Geometric Means

Geometric mean levels of urinary barium for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine and urinary creatinine (data not shown). In NHANES 2001-2002, adjusted geometric mean levels of urinary barium were higher for the group aged 6-11 years than either groups aged 12-19 years or aged 20 years and

### Table 6. Barium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **1.40** (1.26-1.56) | **1.41** (1.28-1.54) | **2.54** (2.18-2.89) | **4.68** (3.85-5.47) | **6.27** (5.47-8.09) | 2180 |
| | 01-02 | **1.44** (1.31-1.58) | **1.48** (1.35-1.63) | **2.76** (2.51-3.03) | **4.58** (4.14-4.95) | **6.24** (5.28-7.27) | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **2.37** (1.68-3.32) | **2.35** (1.83-2.92) | **4.46** (2.55-6.46) | **8.77** (3.75-22.0) | **11.4** (5.45-22.0) | 297 |
| | 01-02 | **2.20** (1.91-2.52) | **2.41** (2.19-2.83) | **3.91** (3.29-4.51) | **4.96** (4.58-6.00) | **6.71** (5.20-8.47) | 368 |
| 12-19 years | 99-00 | **1.51** (1.34-1.70) | **1.39** (1.26-1.59) | **2.48** (1.97-3.06) | **4.36** (3.23-5.39) | **6.95** (4.24-11.4) | 621 |
| | 01-02 | **1.45** (1.33-1.59) | **1.56** (1.31-1.77) | **2.88** (2.68-3.12) | **4.50** (3.84-5.20) | **5.55** (4.81-6.10) | 762 |
| 20 years and older | 99-00 | **1.30** (1.19-1.42) | **1.33** (1.20-1.45) | **2.32** (2.08-2.62) | **4.29** (3.62-4.91) | **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 |
| **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) | **4.50** (3.73-4.95) | **5.42** (4.81-7.51) | 1334 |
| Females | 99-00 | **1.49** (1.27-1.74) | **1.46** (1.29-1.68) | **2.65** (2.13-3.46) | **4.86** (3.96-6.38) | **7.36** (5.25-11.3) | 1097 |
| | 01-02 | **1.59** (1.45-1.75) | **1.63** (1.48-1.79) | **2.98** (2.75-3.30) | **4.76** (4.38-5.31) | **6.97** (5.86-7.52) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **1.21** (1.10-1.33) | **1.17** (1.03-1.37) | **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) | **4.95** (4.24-6.80) | 682 |
| Non-Hispanic blacks | 99-00 | **.881** (.703-1.11) | **.904** (.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) | **.920** (.754-1.11) | **1.64** (1.44-2.03) | **2.86** (2.48-3.37) | **3.96** (3.52-4.68) | 667 |
| 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) | **4.95** (4.55-5.41) | **6.71** (5.57-7.64) | 1132 |

older. Levels in the group aged 12-19 years were higher than the group aged 20 years and older. Levels in non-Hispanic whites were higher than in non-Hispanic blacks and Mexican Americans. It is unknown whether these differences associated with age or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of barium in urine does not mean that the level of barium causes an adverse health effect. Whether barium at the levels reported here is a cause for health concern is not yet known; more research is needed. These urine barium data provide physicians with a reference range so that they can determine whether people have been exposed to higher levels of barium than are found in the general population. These data will also help scientists plan and conduct research about exposure to barium and health effects.

## Figure 2. Barium (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
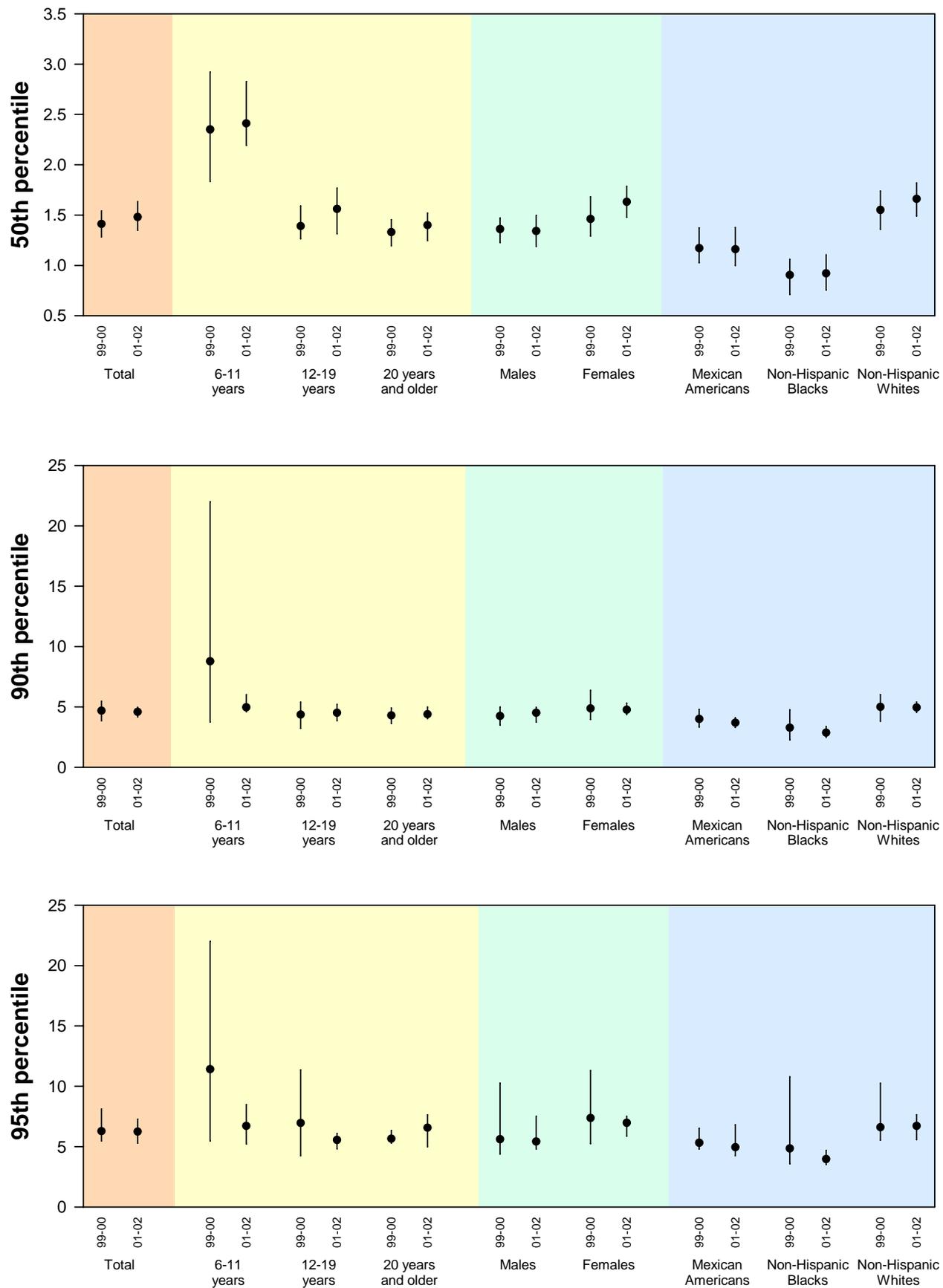
# Beryllium

CAS No. 7440-41-7

## General Information

Pure beryllium is a hard gray metal. The lightest of all metals, beryllium can be found in mineral rocks, coal, soil, and volcanic dust. Beryllium compounds are commercially mined, and the beryllium is refined for use in mirrors and in special metal alloys used in 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.

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. In the workplace, beryllium dust enters the body primarily through the lungs, where it remains for years, but there are little data available on how the metal accumulates in the lungs. Low-level beryllium exposure occurs through breathing air, eating food, or drinking water containing the metal. Small amounts of beryllium dust can enter air from burning coal and oil.

Beryllium may be harmful if inhaled. The effects depend on the concentration of beryllium in the inhaled air and the duration of air exposure. Air levels greater than 100 $\mu g/m^3$ can result in erythema and edema of the lung mucosa, producing pneumonitis. Chronic beryllium disease, or berylliosis, is a granulomatous interstitial lung disease that results from chronic beryllium inhalation and immunologic response. Skin contact with beryllium may also produce dermatitis, and some people demonstrate a hypersensitivity reaction to beryllium. Contact dermatitis and subcutaneous nodules have been reported with skin

## Table 7. Beryllium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

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

< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample. See Appendix A for LODs.

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

exposure to beryllium.

Workplace air standards for external exposure have been established by OSHA and ACGIH. NTP considers beryllium to be a known carcinogen. IARC states that beryllium is an animal carcinogen, and sufficient evidence exists to consider beryllium and beryllium compounds as carcinogenic in people, causing lung and central nervous system cancers. More information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA's IRIS Web site at http://www.epa.gov/iris and from ATSDR's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

### Interpreting Levels of Urinary Beryllium Reported in the Tables

Urinary beryllium levels were measured in a subsample of NHANES participants aged 6 years old and older. Participants were selected within the specified age range

to be a representative sample of the U.S. population. Comparable to the 1999-2000 subsample analysis, levels of beryllium were mostly undetectable. Previous studies have reported urinary levels for general populations as either undetectable concentrations or have not had comparable detection limits (Komaromy-Hiller et al., 2000; Minoia et al., 1990; Paschal et al., 1998). A summary of reference ranges taken from previous studies suggested that a true reference range for urinary beryllium is below the detection limits in past applications (less than 1 µg/L) (Hamilton et al., 1994). Apostoli and Schaller (2001) suggest that previous detection limits are inadequate to quantitate normal human exposure. In that study, urinary beryllium in workers correlated with air exposure measures, and when air levels were below the recommended threshold limit value, urinary beryllium concentrations ranged from 0.12 to 0.15 µg/L. The 95th percentiles in this *Report* for people aged 12-19 years and for males (0.14 µg/L and 0.13 µg/L, respectively) are similar to those values reported by Apostoli and Schaller (2001). Because the

### Table 8. Beryllium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 2465 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 340 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 368 |
| 12-19 years | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 719 |
| | 01-02 | * | < LOD | < LOD | < LOD | **.231** (.173-.273) | 762 |
| 20 years and older | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1406 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1227 |
| | 01-02 | * | < LOD | < LOD | < LOD | **.281** (.237-.333) | 1334 |
| Females | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1238 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 884 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 682 |
| Non-Hispanic blacks | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 568 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 667 |
| Non-Hispanic whites | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 822 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1132 |

< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample. See Appendix A for LODs.

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

detection limit documented in this *Report* was 0.13 μg/L and because most of the samples were undetectable, these NHANES 1999-2002 levels are likely to be lower than levels considered safe for workers.

Finding a measurable amount of beryllium in urine does not mean that the level of beryllium causes an adverse health effect. Whether beryllium at the levels reported here is a cause for health concern is not yet known; more research is needed. These urinary beryllium data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of beryllium than are found in the general population. These data will also help scientists plan and conduct research about exposure to beryllium and health effects.

# Cadmium

CAS No. 7440-43-9

## General Information

Cadmium is a soft, malleable, bluish-white metal that is obtained chiefly as a by-product during the processing of zinc-containing ores (principally sphalerite, as zinc sulfide) and to a lesser extent during the refining of lead and copper from sulfide ore. The predominant commercial use of cadmium is in the manufacture of batteries (78% of uses). The use of cadmium in pigments accounts for 12% of consumption; in coatings and plating another 8% is used, and the remainder is used in stabilizers for plastic (1.5%), and nonferrous alloys and other uses (0.5%). From 2001 through 2004, the commercial use of cadmium declined approximately 70% in response to environmental concerns (U.S. Geological

Survey, 2004). Emissions of cadmium into the environment occur mainly via anthropogenic activities, such as secondary lead smelting, primary copper smelting, primary lead production, hazardous and municipal waste incineration, and petroleum refining (U.S. EPA, 1992).

Cadmium is absorbed via inhalation and ingestion. Inhalation of cigarette smoke is a predominant source in smokers. For nonsmokers who are not exposed to cadmium in the workplace, food is the largest source of cadmium intake and absorption. An analysis of food-intake rates and food-cadmium concentrations for the U.S. population recently estimated a geometric mean daily cadmium intake of 18.9 µg/day, or 0.4 µg/kg/day

## Table 9. Cadmium in blood

Geometric mean and selected percentiles of blood concentrations (in µg/L) for the U.S. population aged 1 year and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 1 and older** | 99-00 | **.412** (.378-.449) | **.300** (.300-.400) | **.600** (.500-.600) | **1.00** (.900-1.00) | **1.30** (1.20-1.40) | 7970 |
| | 01-02 | * | **.300** (<LOD-.300) | **.400** (.400-.500) | **.900** (.900-1.10) | **1.30** (1.20-1.60) | 8945 |
| **Age group** | | | | | | | |
| 1-5 years | 99-00 | * | < LOD | **.300** (<LOD-.300) | **.400** (.300-.400) | **.400** (.300-.400) | 723 |
| | 01-02 | * | < LOD | < LOD | < LOD | **.300** (<LOD-.300) | 898 |
| 6-11 years | 99-00 | * | < LOD | **.300** (<LOD-.300) | **.400** (.300-.400) | **.400** (.400-.500) | 905 |
| | 01-02 | * | < LOD | < LOD | < LOD | **.400** (.300-.400) | 1044 |
| 12-19 years | 99-00 | **.333** (.304-.366) | **.300** (<LOD-.300) | **.300** (.300-.400) | **.800** (.600-.900) | **1.10** (.900-1.10) | 2135 |
| | 01-02 | * | < LOD | **.300** (<LOD-.300) | **.400** (.400-.500) | **.800** (.600-1.10) | 2231 |
| 20 years and older | 99-00 | **.468** (.426-.513) | **.400** (.300-.400) | **.600** (.600-.700) | **1.00** (1.00-1.10) | **1.50** (1.40-1.60) | 4207 |
| | 01-02 | * | **.300** (.300-.400) | **.600** (.500-.600) | **1.10** (.900-1.20) | **1.60** (1.30-1.80) | 4772 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.403** (.368-.441) | **.400** (.300-.400) | **.600** (.500-.600) | **1.00** (.900-1.10) | **1.30** (1.20-1.50) | 3913 |
| | 01-02 | * | **.300** (<LOD-.300) | **.400** (.400-.500) | **.900** (.900-1.10) | **1.40** (1.20-1.80) | 4339 |
| Females | 99-00 | **.421** (.386-.460) | **.300** (.300-.400) | **.600** (.500-.600) | **1.00** (.800-1.00) | **1.30** (1.10-1.40) | 4057 |
| | 01-02 | * | **.300** (.300-.400) | **.500** (.500-.600) | **1.00** (.900-1.10) | **1.40** (1.20-1.60) | 4606 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.395** (.367-.424) | **.400** (.300-.400) | **.400** (.400-.500) | **.700** (.700-.900) | **1.10** (.900-1.30) | 2742 |
| | 01-02 | * | < LOD | **.300** (.300-.400) | **.600** (.500-.700) | **1.00** (.700-1.30) | 2268 |
| Non-Hispanic blacks | 99-00 | **.393** (.361-.427) | **.300** (.300-.400) | **.600** (.500-.600) | **1.00** (.800-1.10) | **1.40** (1.10-1.50) | 1842 |
| | 01-02 | * | < LOD | **.400** (.400-.500) | **1.00** (.900-1.00) | **1.40** (1.20-1.50) | 2219 |
| Non-Hispanic whites | 99-00 | **.420** (.376-.470) | **.400** (.300-.400) | **.500** (.500-.600) | **1.00** (.900-1.10) | **1.30** (1.20-1.40) | 2716 |
| | 01-02 | * | < LOD | **.500** (.500-.600) | **.900** (.900-1.10) | **1.40** (1.20-1.80) | 3806 |

< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample. See Appendix A for LODs.

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

(Choudhury et al., 2001). Although several studies have found that the average gastrointestinal absorption of dietary cadmium is on the order of 5% (Diamond et al., 2003), two balance studies have suggested that this value may be five- to ten-fold greater in young women than in the general population (Kikuchi et al., 2003; Horiguchi et al., 2004*a*). With chronic exposure, cadmium accumulates in the liver and the kidney, with one-third to one half of the total amount accumulating in the kidney (Nordberg and Nordberg, 2001). In both organs, cadmium tightly binds to metallothionein, an inducible metal-binding protein that provides protection against many of cadmium's toxic effects (Klaasen et al., 1999). The estimated half-life of cadmium in the kidney is one to four decades (ATSDR, 1999; Diamond et al., 2003).

  The kidney is a critical target for cadmium. Renal tubular damage and glomerular damage can be caused by high-dose chronic exposure, which may occur in people who are occupationally exposed, and is manifested by irreversible proteinuria and progressive reductions in glomerular filtration rate (Roels et al., 1999). Increased urinary excretion of calcium and phosphorus and decreased hydroxylation of vitamin D metabolites that accompany advanced tubular damage may result in overt, and often painful, osteomalacia or osteoporosis, typified by a condition known as "Itai-Itai disease" that afflicted women living in a cadmium-polluted region of Japan. Several recent epidemiological investigations in Belgium (Staessen et al., 1996; Hotz et al., 1999; Staessen et al., 1999), Sweden (Jarup et al., 2000; Alfven et al., 2002; Olsson et al., 2002), Japan (Suwazono et al., 2000; Ezaki et al., 2003; Horiguchi et al., 2004*b*) China (Jin et al., 2004), and the United States (Noonan et al., 2002) have detected an association between relatively low-level environmental cadmium exposure and biomarkers of renal dysfunction or diminished bone mineral density. Environmental exposure from cadmium pollution has been linked to an increased rate of end-stage renal disease in a Swedish population residing in the vincinity of two battery manufacturing plants (Hellstrom et al., 2001). Although all the mechanisms of cadmium toxicity

## Table 10. Cadmium in urine

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.193** (.169-.220) | **.232** (.214-.249) | **.475** (.436-.519) | **.858** (.763-.980) | **1.20** (1.06-1.33) | 2257 |
| | 01-02 | **.210** (.189-.235) | **.229** (.207-.255) | **.458** (.423-.482) | **.839** (.753-.919) | **1.20** (1.07-1.28) | 2690 |
| **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 |
| 12-19 years | 99-00 | **.092** (.067-.126) | **.128** (.107-.148) | **.202** (.183-.232) | **.329** (.272-.372) | **.424** (.366-.596) | 648 |
| | 01-02 | **.109** (.087-.136) | **.135** (.114-.157) | **.210** (.189-.247) | **.327** (.289-.366) | **.442** (.366-.480) | 762 |
| 20 years and older | 99-00 | **.281** (.253-.313) | **.306** (.261-.339) | **.551** (.510-.621) | **.979** (.836-1.13) | **1.31** (1.13-1.57) | 1299 |
| | 01-02 | **.273** (.249-.299) | **.280** (.261-.308) | **.545** (.493-.607) | **.955** (.855-1.06) | **1.28** (1.20-1.43) | 1560 |
| **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) | **.870** (.741-1.03) | **1.22** (1.12-1.38) | 1335 |
| Females | 99-00 | **.187** (.153-.229) | **.239** (.220-.255) | **.492** (.456-.540) | **.806** (.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 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.191** (.157-.233) | **.202** (.167-.221) | **.438** (.351-.551) | **.813** (.686-.977) | **1.12** (.886-1.38) | 780 |
| | 01-02 | **.160** (.135-.189) | **.181** (.171-.198) | **.321** (.285-.362) | **.559** (.430-.733) | **.766** (.633-1.15) | 683 |
| Non-Hispanic blacks | 99-00 | **.283** (.208-.387) | **.312** (.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) | **.580** (.476-.713) | **1.04** (.843-1.38) | **1.51** (1.28-1.74) | 667 |
| Non-Hispanic whites | 99-00 | **.175** (.148-.206) | **.220** (.194-.246) | **.455** (.388-.510) | **.797** (.714-1.01) | **1.17** (.963-1.47) | 760 |
| | 01-02 | **.204** (.179-.231) | **.221** (.191-.255) | **.445** (.394-.479) | **.813** (.717-.875) | **1.17** (.989-1.24) | 1132 |

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

are uncertain, key factors may involve perturbation of zinc-dependent biochemical processes, induction of oxidative stress, aberrant gene expression, estrogenic effects (Johnson et al., 2003), or altered cell signaling and steroidogenesis (Misra et al., 2003; Waalkes, 2003; Henson and Chedrese, 2004).

Acute and heavy airborne exposure to dusts and fumes, as may occur from welding on cadmium-alloyed metals, may result in severe, potentially fatal pneumonitis (Fernandez et al., 1996). Chronic inhalation exposure to cadmium particulate has been associated with changes in pulmonary function and chest radiography consistent with emphysema (Davison et al., 1988). Among U.S. adult smokers and former smokers studied in NHANES III, increases in urinary cadmium were associated with obstructive changes in pulmonary function (Mannino et al., 2004). Workplace exposure to airborne cadmium particulate has been associated with decrements in olfactory function (Mascagni et al., 2003). Animal studies have demonstrated reproductive and teratogenic

effects. Two recent small epidemiologic studies have noted a positive association of environmental cadmium levels in maternal urine or blood with gestational age (Nishijo et al., 2002) and birth height (Zhang et al., 2004). NTP has determined that cadmium is a known human carcinogen. Potential modes of action have recently been reviewed (Waalkes, 2003). Information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA's IRIS Web site at http://www.epa.gov/iris and from ATSDR's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

**Interpreting Levels of Cadmium in Blood and Urine Reported in the Tables**

In the NHANES 2001-2002 sample, blood cadmium levels were measured in all participants aged 1 year and older, and urine cadmium levels were measured in a sample of people aged 6 years and older. Participants were selected to be a representative sample of the U.S.

## Table 11. Cadmium in urine (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.181** (.157-.209) | **.219** (.199-.238) | **.423** (.391-.446) | **.712** (.645-.757) | **.933** (.826-1.07) | 2257 |
| | 01-02 | **.199** (.181-.218) | **.212** (.194-.232) | **.404** (.377-.440) | **.690** (.630-.754) | **.917** (.813-.998) | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | * | **.085** (.063-.107) | **.147** (.123-.182) | **.210** (.171-.316) | **.300** (.184-.607) | 310 |
| | 01-02 | **.075** (.059-.094) | **.100** (.083-.112) | **.166** (.136-.192) | **.233** (.206-.281) | **.291** (.221-.440) | 368 |
| 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) | **.136** (.123-.143) | **.191** (.175-.234) | **.280** (.234-.321) | 762 |
| 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) | **.776** (.691-.850) | **.979** (.874-1.12) | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.154** (.131-.182) | **.174** (.158-.191) | **.329** (.293-.382) | **.617** (.537-.700) | **.788** (.696-.929) | 1121 |
| | 01-02 | **.159** (.143-.177) | **.168** (.157-.182) | **.334** (.304-.364) | **.532** (.491-.653) | **.757** (.690-.856) | 1334 |
| 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 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.175** (.137-.223) | **.181** (.144-.225) | **.331** (.266-.418) | **.612** (.441-.828) | **.843** (.674-1.13) | 780 |
| | 01-02 | **.156** (.136-.178) | **.170** (.150-.184) | **.282** (.263-.340) | **.501** (.388-.614) | **.693** (.507-.839) | 682 |
| Non-Hispanic blacks | 99-00 | **.183** (.140-.240) | **.201** (.168-.241) | **.414** (.343-.472) | **.658** (.516-.827) | **.873** (.722-.962) | 546 |
| | 01-02 | **.190** (.156-.232) | **.195** (.174-.225) | **.385** (.336-.449) | **.676** (.559-.850) | **.917** (.725-1.08) | 667 |
| 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 |

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

population. Blood cadmium reflects both recent and cumulative exposures. During typical environmental exposure, urinary cadmium predominantly reflects cumulative exposure and the concentration of cadmium in the kidney (Nordberg and Nordberg, 2001; Lauwerys and Hoet, 2001 Satarug et al., 2002).

A general population survey of approximately 4,700 adults in Germany in 1998 found levels of cadmium in blood and urine that were also similar or slightly higher than the adult values reported in the 1999-2000 and 2001-2002 samples (Becker et al., 2002; Becker et al., 2003). Creatinine-corrected urine cadmium values obtained in a study of 361 subjects from a U.S. community, where smelting activity had occurred in the past, and an unexposed comparison community were also similar to the corresponding values in this *Report* (Noonan et al., 2002). A general population survey of 10,753 adult Japanese women found geometric mean urinary cadmium levels that were approximately four-to-five-fold higher than the levels found for U.S. adults in this *Report*. (Ezaki et al., 2003). People who are occupationally exposed may have blood and urine levels that are higher than levels in the general population. The 95th percentiles for blood cadmium levels in this *Report* are less than the OSHA criterion (OSHA, 29 CFR 1910.1027) for blood cadmium (5 µg/L), and the 95th percentile for urine cadmium is less than the OSHA criterion for urine cadmium (3 µg/gram of creatinine). Occupational criteria are provided here for comparison only, not to imply a safety level for general population exposure.

In recent studies, levels of urinary cadmium greater than or equal to 1 µg/gram of creatinine have been associated with increases in urinary protein markers of renal tubular function (Jarup et al., 2000; Moriguchi et al., 2004; Noonan et al., 2002). In addition, a decrease in bone density has been correlated with urinary cadmium excretion among middle-aged women with a mean urinary cadmium concentration of approximately 1 µg/gram creatinine (Staessen et al., 1999), and among women older than 60 years, the odds of low bone-mineral density increased by nearly three-fold when the blood cadmium level 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, approach these cited 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.

**Comparing Adjusted Geometric Means**

Geometric mean levels of blood cadmium in the NHANES 2001-2002 sample could not be calculated for this *Report* due to an insufficient number of samples with detectable levels of cadmium. The adjusted geometric mean levels of blood cadmium for the demographic groups were compared previously in the NHANES 1999-2000 sample after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). Adjusted geometric mean levels of blood cadmium were slightly higher in the group aged 20 years and older than either of the groups aged 6-11 or the 12-19 years; and the group aged 12-19 years was higher than the group aged 6-11 years. Females had slightly higher blood cadmium levels than males. Mexican Americans had higher adjusted geometric mean levels of blood cadmium than non-Hispanic whites or non-Hispanic blacks; and non-Hispanic blacks had higher blood cadmium levels than non-Hispanic whites. Similar relationships for age and gender were found in a study of NHANES III participants (Paschal et al., 2000).

Due to a recently demonstrated interference from molybdenum oxide when measuring low-level urinary cadmium using the ICP-MS method, both the 1999-2000 and 2001-2002 data were corrected for this interference based on the molybdenum measurement and expected proportion of molybdenum oxide. Geometric mean levels of urinary cadmium for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine. In the NHANES 2001-2002 sample, the group aged 20 years and older had higher adjusted geometric mean levels of urinary cadmium than in either of the groups aged 6-11 or 12-19 years. Females had higher urinary cadmium levels than males. Higher urinary cadmium values in females than in males have been observed in other general population studies (Olsson et al., 2002) and, as noted previously, may be a possible consequence of increased gastrointestinal absorption of cadmium in females. It is unknown whether these differences associated with age, gender or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of cadmium in blood or urine does not mean that the level of cadmium will result in an adverse health effect. These data provide physicians with a reference range so they can determine whether or not people have been exposed to higher levels of cadmium than are found in the general population. These data also will help scientists plan and conduct research about the relation between exposure to cadmium and health effects.

## Figure 3. Cadmium in urine (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
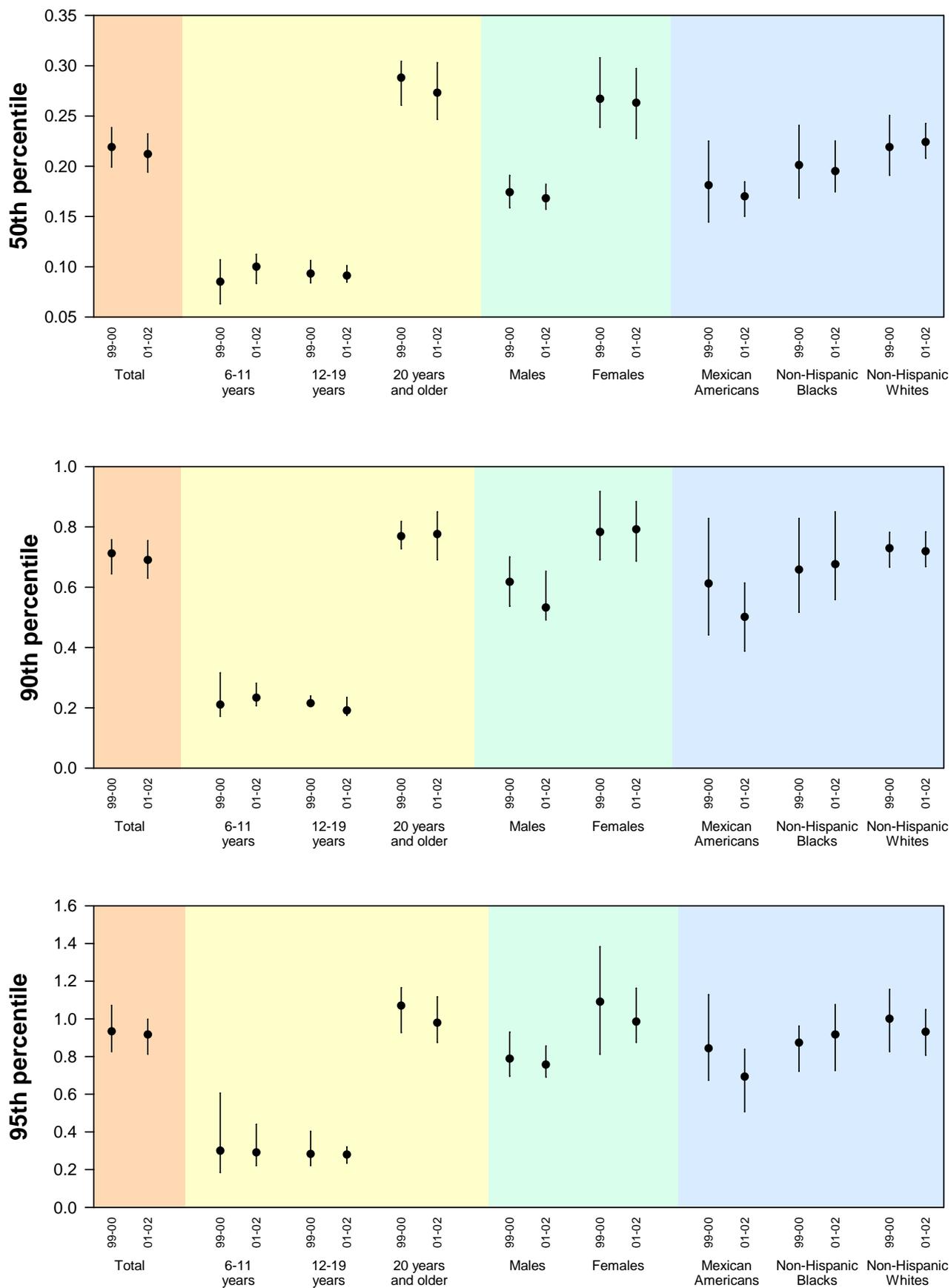
# Cesium

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 commonly used in photomultiplier tubes, vacuum tubes, scintillation counters, infrared lamps, semiconductors, high-power gas-ion devices, and as polymerization catalysts and photographic emulsions. 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 is generally of low toxicity when given to animals. However, cesium hydroxide is corrosive and irritating when concentrations are high. Workplace air standards for external exposure for certain cesium salts

are recommended by NIOSH on the basis of these irritant effects. It is not known whether cesium compounds are carcinogenic.

## Interpreting Levels of Urinary Cesium Reported in the Tables

Urinary cesium levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range to be a representative sample of the U.S. population. In one study of clinically submitted specimens (Komaromy-Hiller et al., 2000), mean urinary cesium concentrations were slightly lower than those reported here. In a small population study of Europeans, Minoia et al. (1990) found average urinary cesium levels to be comparable to levels in this *Report*. Median values in the NHANES 1999-2000 and 2001-2002 subsamples are more than

## Table 12. Cesium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **4.35** (4.00-4.74) | **4.80** (4.40-5.30) | **7.10** (6.50-7.70) | **9.60** (8.80-10.3) | **11.4** (10.2-12.9) | 2464 |
| | 01-02 | **4.81** (4.40-5.26) | **5.49** (5.09-5.89) | **7.91** (7.47-8.39) | **10.4** (9.56-11.4) | **12.6** (11.1-13.8) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **4.87** (4.08-5.81) | **5.60** (4.60-6.70) | **7.30** (6.70-8.00) | **9.00** (7.90-10.1) | **9.70** (8.90-10.4) | 340 |
| | 01-02 | **4.87** (4.08-5.82) | **5.61** (4.69-6.52) | **7.96** (6.77-8.84) | **9.79** (8.64-10.6) | **11.1** (10.2-12.4) | 368 |
| 12-19 years | 99-00 | **4.55** (4.09-5.05) | **5.10** (4.30-5.60) | **6.80** (6.10-7.70) | **8.80** (8.00-9.40) | **10.4** (8.90-12.3) | 718 |
| | 01-02 | **5.22** (4.57-5.95) | **5.62** (5.13-6.12) | **7.55** (7.13-8.04) | **9.71** (9.12-11.1) | **12.0** (10.0-15.0) | 762 |
| 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** (8.80-10.5) | **11.6** (10.2-13.2) | 1406 |
| | 01-02 | **4.74** (4.32-5.20) | **5.43** (5.05-5.87) | **7.96** (7.43-8.52) | **10.6** (9.73-11.5) | **12.8** (11.2-14.2) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **4.84** (4.35-5.38) | **5.50** (4.60-5.90) | **7.50** (6.90-8.20) | **9.70** (8.60-10.7) | **11.6** (10.3-13.0) | 1226 |
| | 01-02 | **5.34** (4.89-5.84) | **6.11** (5.61-6.64) | **8.26** (7.84-9.08) | **10.8** (10.1-12.1) | **12.8** (11.3-15.0) | 1335 |
| Females | 99-00 | **3.95** (3.63-4.29) | **4.50** (4.10-4.80) | **6.60** (6.20-7.30) | **9.10** (8.30-9.90) | **11.1** (9.90-12.9) | 1238 |
| | 01-02 | **4.36** (3.95-4.81) | **4.87** (4.45-5.25) | **7.29** (6.71-8.01) | **9.77** (9.07-11.0) | **12.4** (10.4-13.8) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **4.32** (3.82-4.89) | **4.70** (4.20-5.10) | **6.60** (6.20-7.10) | **9.10** (8.00-9.80) | **10.9** (9.50-12.6) | 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 |
| Non-Hispanic blacks | 99-00 | **4.94** (4.33-5.64) | **5.40** (4.80-6.30) | **7.40** (6.80-8.20) | **9.80** (8.80-10.8) | **11.5** (9.80-13.1) | 568 |
| | 01-02 | **4.93** (4.70-5.17) | **5.31** (5.05-5.63) | **7.36** (6.97-7.59) | **9.44** (8.71-9.68) | **10.7** (10.1-12.3) | 667 |
| Non-Hispanic whites | 99-00 | **4.25** (3.83-4.72) | **4.70** (4.20-5.50) | **7.10** (6.50-7.80) | **9.60** (8.80-10.4) | **11.7** (10.3-13.3) | 821 |
| | 01-02 | **4.77** (4.27-5.32) | **5.46** (4.97-6.03) | **7.97** (7.43-8.55) | **10.4** (9.54-11.4) | **12.6** (11.0-13.8) | 1132 |

twice the median values reported in a nonrandom subsample from NHANES III (1988-1994) (Paschal et al., 1998), which may be due to methodologic, population, or exposure differences.

## Comparing Adjusted Geometric Means

Geometric mean levels of urinary cesium for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). In NHANES 2001-2002, adjusted geometric mean levels of urinary cesium were slightly higher for children aged 6-11 years than for either of the groups aged 12-19 years or 20 years and older. The group aged 12-19 years had lower levels than the 20 year and older group. Mexican Americans had higher levels than non-Hispanic blacks. Non-Hispanic whites had higher levels than non-Hispanic blacks. It is unknown whether these differences associated with age or race/ethnicity represent

differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of cesium in urine does not mean that the level of cesium causes an adverse health effect. Whether cesium at the levels reported here is a cause for health concern is not yet known; more research is needed. These urinary cesium data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of cesium than levels found in the general population. These data will also help scientists plan and conduct research about exposure to cesium and health effects.

## Table 13. Cesium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **4.10** (3.96-4.25) | **4.12** (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 |
| **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) | **9.89** (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) | **9.19** (8.35-11.9) | **11.9** (9.38-12.3) | 368 |
| 12-19 years | 99-00 | **3.43** (3.29-3.58) | **3.52** (3.29-3.68) | **4.35** (4.17-4.56) | **5.31** (4.97-5.79) | **6.56** (5.33-8.09) | 718 |
| | 01-02 | **3.73** (3.41-4.08) | **3.55** (3.36-3.74) | **4.74** (4.40-5.13) | **6.10** (5.35-7.63) | **8.05** (6.44-9.82) | 762 |
| 20 years and older | 99-00 | **4.08** (3.88-4.29) | **4.06** (3.85-4.29) | **5.38** (5.04-5.85) | **7.17** (6.84-7.58) | **8.60** (7.91-9.30) | 1406 |
| | 01-02 | **4.54** (4.30-4.78) | **4.42** (4.20-4.59) | **5.94** (5.64-6.40) | **8.15** (7.46-8.97) | **10.2** (8.74-11.7) | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | **3.78** (3.65-3.91) | **3.78** (3.60-3.96) | **4.96** (4.72-5.20) | **6.45** (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 |
| Females | 99-00 | **4.43** (4.20-4.68) | **4.44** (4.14-4.77) | **5.92** (5.36-6.47) | **7.70** (7.16-8.06) | **9.38** (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) | **8.47** (7.84-9.79) | **10.3** (8.95-12.2) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **3.99** (3.73-4.25) | **3.95** (3.64-4.13) | **5.09** (4.79-5.38) | **6.64** (6.08-7.10) | **7.96** (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 |
| Non-Hispanic blacks | 99-00 | **3.21** (2.90-3.56) | **3.26** (3.05-3.44) | **4.30** (4.00-4.55) | **5.49** (5.00-5.98) | **6.33** (5.91-7.04) | 568 |
| | 01-02 | **3.38** (3.19-3.57) | **3.34** (3.05-3.60) | **4.41** (4.15-4.78) | **5.87** (5.63-6.29) | **6.75** (6.41-7.03) | 667 |
| Non-Hispanic whites | 99-00 | **4.26** (4.07-4.47) | **4.28** (4.05-4.50) | **5.63** (5.26-6.05) | **7.27** (6.84-7.83) | **8.68** (7.93-9.38) | 821 |
| | 01-02 | **4.81** (4.55-5.08) | **4.62** (4.42-4.96) | **6.33** (5.91-6.68) | **8.46** (7.84-9.39) | **10.3** (9.04-11.8) | 1132 |

# Figure 4. Cesium in urine (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
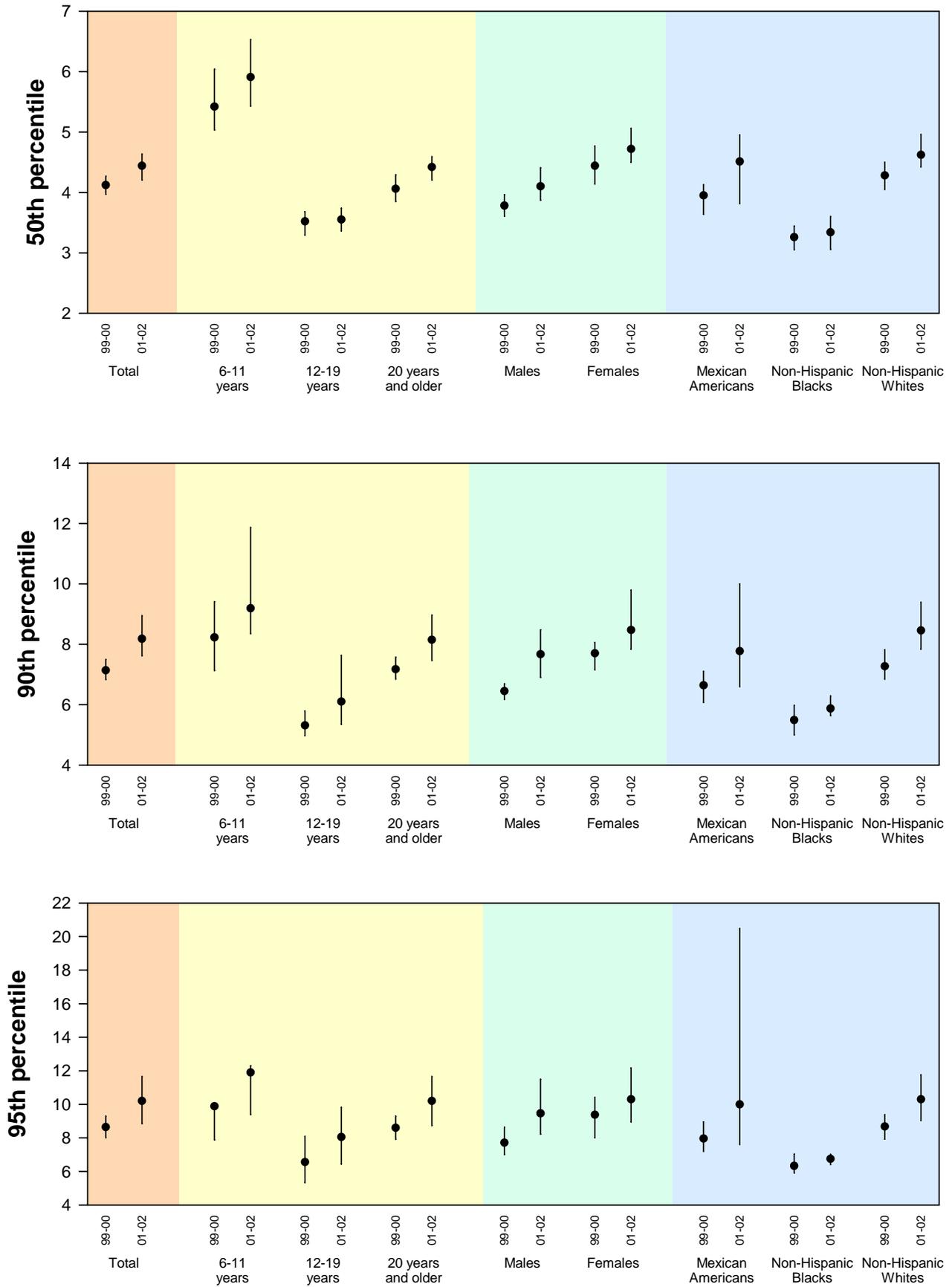
# Cobalt

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 the manufacture of superalloys used in gas turbines in aircraft engines, hard-metal alloys (in combination with 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 the production of oil and gas and in the synthesis of polyester and other materials. Cobalt compounds are also used in the manufacture of battery electrodes, steel-belted radial tires, automobile airbags, diamond-polishing

wheels, and magnetic recording media.

Cobalt occurs naturally in airborne dust, seawater, and many types of soil. It is also emitted into the environment from burning coal and oil and from 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 fabricated from cobalt alloys (Lhotka et al., 2003). Exposure in the workplace may come from electroplating, the refining or processing of alloys, the grinding of tungsten carbide-type, hard-metal cutting tools, and the use of diamond-polishing wheels containing cobalt metal. Workplace standards for external air exposure to cobalt and several of its compounds have been established by OSHA and ACGIH.

## Table 14. Cobalt

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.375** (.336-.419) | **.400** (.360-.440) | **.630** (.570-.670) | **.940** (.890-1.03) | **1.32** (1.16-1.48) | 2465 |
| | 01-02 | **.379** (.355-.404) | **.410** (.380-.430) | **.610** (.570-.660) | **.930** (.860-1.00) | **1.27** (1.15-1.44) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.499** (.427-.583) | **.520** (.430-.600) | **.740** (.610-.900) | **1.03** (.860-1.12) | **1.22** (1.03-1.50) | 340 |
| | 01-02 | **.452** (.377-.543) | **.510** (.430-.610) | **.710** (.660-.810) | **1.07** (.940-1.21) | **1.28** (1.17-1.53) | 368 |
| 12-19 years | 99-00 | **.519** (.463-.581) | **.520** (.480-.550) | **.810** (.670-.890) | **1.16** (1.01-1.47) | **1.52** (1.26-2.56) | 719 |
| | 01-02 | **.515** (.469-.564) | **.520** (.470-.570) | **.750** (.690-.840) | **1.23** (1.07-1.32) | **1.59** (1.37-1.99) | 762 |
| 20 years and older | 99-00 | **.343** (.305-.386) | **.360** (.320-.410) | **.560** (.510-.640) | **.880** (.800-.950) | **1.28** (1.07-1.39) | 1406 |
| | 01-02 | **.352** (.333-.373) | **.370** (.350-.400) | **.550** (.520-.590) | **.860** (.790-.930) | **1.15** (1.04-1.42) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.371** (.331-.416) | **.400** (.360-.440) | **.580** (.530-.630) | **.810** (.730-.890) | **1.01** (.900-1.12) | 1227 |
| | 01-02 | **.367** (.338-.399) | **.390** (.360-.410) | **.540** (.510-.590) | **.780** (.740-.840) | **1.05** (.960-1.14) | 1335 |
| Females | 99-00 | **.379** (.333-.431) | **.410** (.340-.460) | **.670** (.590-.790) | **1.17** (.930-1.36) | **1.49** (1.28-1.98) | 1238 |
| | 01-02 | **.390** (.364-.417) | **.430** (.390-.440) | **.660** (.620-.700) | **1.05** (.980-1.16) | **1.44** (1.22-1.81) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.418** (.348-.502) | **.470** (.370-.530) | **.660** (.620-.760) | **1.05** (.950-1.19) | **1.47** (1.25-1.67) | 884 |
| | 01-02 | **.398** (.373-.424) | **.420** (.400-.450) | **.640** (.600-.710) | **.950** (.850-1.03) | **1.20** (1.06-1.48) | 683 |
| Non-Hispanic blacks | 99-00 | **.434** (.405-.465) | **.420** (.390-.470) | **.680** (.620-.750) | **1.15** (1.02-1.25) | **1.45** (1.23-2.04) | 568 |
| | 01-02 | **.435** (.388-.487) | **.410** (.380-.440) | **.650** (.540-.810) | **1.15** (.840-1.63) | **1.75** (1.32-2.22) | 667 |
| Non-Hispanic whites | 99-00 | **.369** (.316-.431) | **.400** (.340-.450) | **.620** (.550-.700) | **.930** (.820-1.07) | **1.29** (1.02-1.65) | 822 |
| | 01-02 | **.359** (.327-.394) | **.380** (.350-.430) | **.580** (.520-.650) | **.870** (.800-.930) | **1.16** (1.04-1.32) | 1132 |

Cobalt constitutes 4% by weight of vitamin B-12 (cobalamin), an essential human nutrient. A nutritional requirement for cobalt not contained in dietary cobalamin has not been established. Cobalt is absorbed by oral and pulmonary routes. Human studies with ^{60}Co administered as soluble cobalt chloride have measured 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% to 15%) exhibiting a half-life of several years (Smith et al., 1972; Mosconi et al., 1994). A portion of cobalt retained for long periods is concentrated in the liver. Lung retention of cobalt compounds of low solubility, such as cobalt oxide, may be prolonged, with some fractions exhibiting pulmonary clearance half-lives of 1-2 years (Hedge et al., 1979). Recent inhalation exposure to soluble cobalt compounds may be monitored effectively by measuring cobalt in urine or blood (Lison et al., 1994).

Most toxic effects of cobalt have been encountered in workplace situations. Cobalt compounds are a recognized cause of allergic contact dermatitis (Dickel et al., 2001; Lisi et al., 2003; Thomssen et al., 2001). Occupational exposure to cobalt-containing dusts has caused occupational asthma (Shirakawa et al., 1989; Pisati and Zedda, 1994). "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 unresolved (Swennen et al., 1993; Linna et al., 2003)

Cobalt was once added as a foaming agent to beer and caused outbreaks of cardiomyopathy among heavy drinkers in the mid-1960s (Alexander et al., 1972). Other case reports have suggested a link between occupational cobalt exposure and cardiomyopathy (Jarvis et al., 1992).

## Table 15. Cobalt (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.353** (.319-.391) | **.328** (.302-.365) | **.515** (.457-.581) | **.810** (.679-.963) | **1.16** (.938-1.50) | 2465 |
| | 01-02 | **.358** (.333-.384) | **.335** (.313-.360) | **.523** (.487-.562) | **.844** (.750-.955) | **1.15** (1.00-1.28) | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.547** (.467-.640) | **.554** (.449-.647) | **.774** (.626-.938) | **1.00** (.830-1.48) | **1.23** (.895-1.50) | 340 |
| | 01-02 | **.552** (.508-.599) | **.548** (.503-.609) | **.756** (.660-.829) | **1.00** (.900-1.25) | **1.30** (1.03-1.73) | 368 |
| 12-19 years | 99-00 | **.391** (.353-.433) | **.378** (.329-.407) | **.535** (.469-.595) | **.824** (.632-1.16) | **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 |
| 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) | **.312** (.293-.336) | **.474** (.435-.513) | **.792** (.704-.955) | **1.15** (.963-1.33) | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.290** (.259-.324) | **.279** (.248-.301) | **.400** (.365-.449) | **.608** (.534-.728) | **.833** (.667-1.10) | 1227 |
| | 01-02 | **.290** (.272-.310) | **.277** (.256-.297) | **.392** (.361-.425) | **.642** (.574-.707) | **.848** (.786-.929) | 1334 |
| Females | 99-00 | **.426** (.378-.479) | **.407** (.362-.457) | **.605** (.550-.694) | **.955** (.781-1.29) | **1.50** (1.11-1.83) | 1238 |
| | 01-02 | **.435** (.404-.468) | **.408** (.382-.438) | **.635** (.560-.708) | **.993** (.867-1.16) | **1.29** (1.12-1.60) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.386** (.339-.439) | **.376** (.333-.419) | **.598** (.500-.669) | **.895** (.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 |
| Non-Hispanic blacks | 99-00 | **.282** (.275-.289) | **.257** (.243-.278) | **.417** (.378-.462) | **.707** (.600-.785) | **.975** (.757-1.60) | 568 |
| | 01-02 | **.298** (.275-.323) | **.268** (.251-.294) | **.444** (.392-.511) | **.728** (.582-.917) | **1.03** (.740-1.55) | 667 |
| Non-Hispanic whites | 99-00 | **.369** (.324-.421) | **.351** (.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 |

Cobalt compounds were formerly used in the treatment of anemia, a probable consequence of their capacity to stimulate erythropoetin production (Goldberg et al., 1988). A recent study observed elevated serum cobalt levels in association with excessive erythrocytosis among residents of a high-altitude mining community (Jefferson et al., 2002). Pharmaceutical preparations of cobalt used in the past as hematinics have been associated with the development of overt hypothyroidism (Kriss et al., 1955), and a subclinical decrement in thyroid production was observed in a study of cobalt-production workers (Swennen et al., 1993).

Cobalt compounds have elicited numerous genotoxic effects in both *in vitro* and *in vivo* assays (De Boeck et al., 2003) and have produced lung cancer in rats and mice following 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 considers cobalt and its compounds as possibly carcinogenic to humans. Information about external exposure (i.e., environmental levels) and health effects is available from ATSDR's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

**Interpreting Levels of Urinary Cobalt Reported in the Tables**

Urinary cobalt levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range to be a representative sample of the U.S. population. The levels of cobalt measured in the adults in the NHANES 2001-2002 also are similar to those found in recent smaller general population surveys of European adults (Kristiansen et al., 1997; White and Sabbioni, 1998). Because concentrations of cobalt in the urine decline rapidly within 24 hours after an exposure ceases (Alexandersson et al., 1988), urinary measurements mainly reflect recent exposure, although substantial occupational exposure can produce elevated urinary levels for many weeks.

Individuals with occupational exposure to cobalt often have urinary cobalt levels that are many times higher than those of the general population (ATSDR, 2004). The ACGIH biological exposure index (BEI) for inorganic forms of cobalt (except insoluble cobalt oxides) is 15 µg/L (ACGIH, 2001). Information about the BEI is provided here for comparison, not to imply that the BEI is a safety level for general population exposure. For workers exposed to cobalt in the air, a distinction should be made between soluble cobalt 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 of better absorption. Correlations between air-exposure levels and urinary cobalt levels in hard-metal fabricators are well documented (Ichikawa et al., 1985; Linnainmaa and Kiilunen, 1997; ACGIH 2001; Kraus et al., 2001; Lauwerys and Hoet, 2001).

**Comparing Adjusted Geometric Means**

Geometric mean levels of urinary cobalt for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). In NHANES 2001-2002, adjusted geometric mean levels of urinary cobalt were slightly higher for children aged 6-11 years than for people aged 12-19 years, with both age groups having higher levels than people aged 20 years and older. Urinary cobalt levels in females were higher than in males, and levels in non-Hispanic blacks were slightly lower than in either Mexican Americans or non-Hispanic whites. Relative higher urinary cobalt levels in females than in males have been noted in other investigations and may reflect increased cobalt uptake by premenopausal women (Kristiansen et al., 1997). It is unknown whether these differences associated with age, gender, or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of cobalt in urine does not mean that the level of cobalt causes an adverse health effect. Whether cobalt at the levels reported here is a cause for health concern is not yet known; more research is needed. These urinary cobalt data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of cobalt than are found in the general population. These data will also help scientists plan and conduct research about exposure to cobalt and health effects.

## Figure 5. Cobalt (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
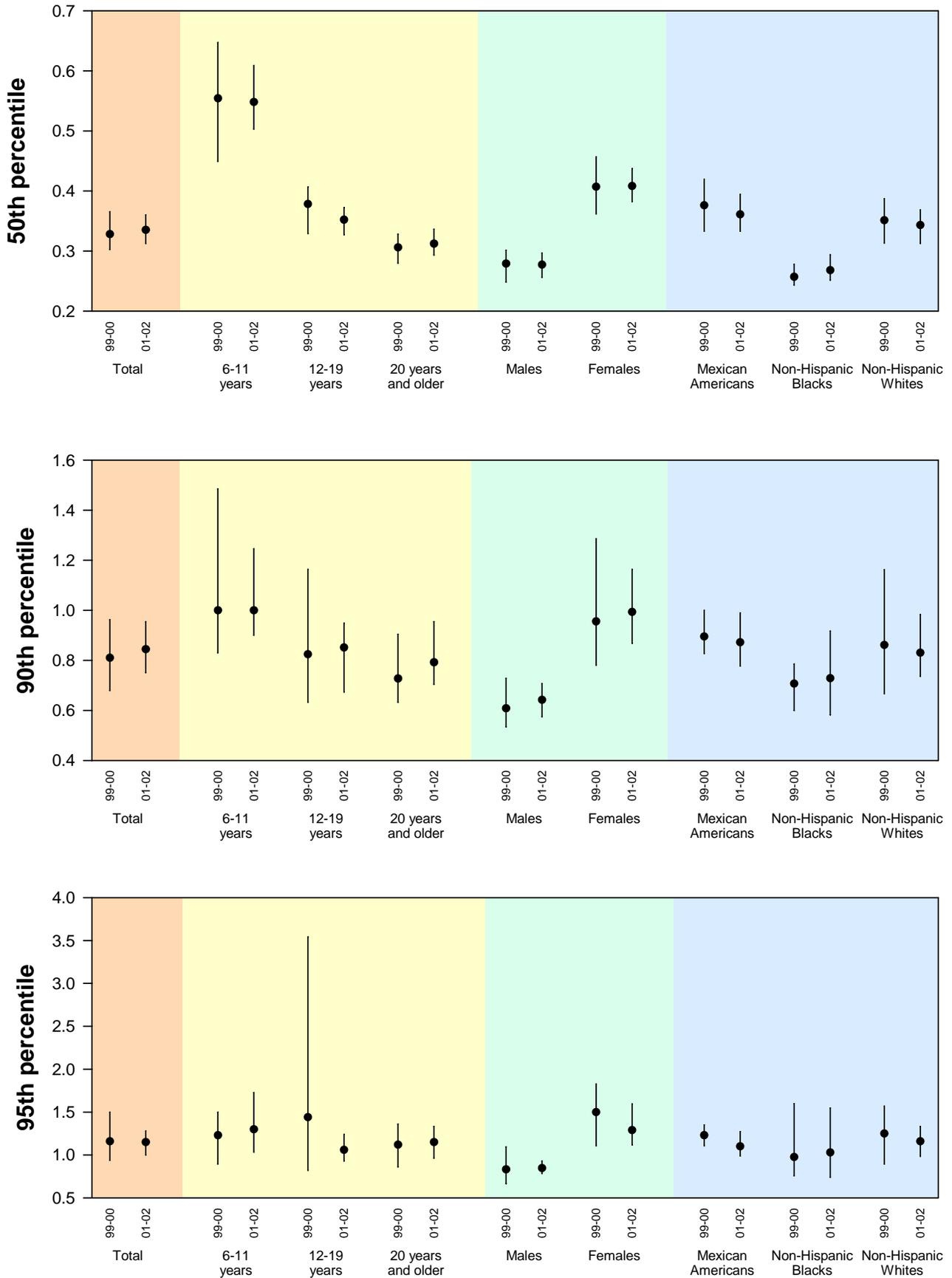
# Lead

CAS No. 7439-92-1

## General Information

Elemental lead, a malleable, dense, blue-gray metal, is a naturally occurring element found in soils and rocks. It can be combined to form inorganic and organic molecules, such as lead phosphate and tetraethyl lead. Lead has a variety of uses in the manufacture of storage batteries; solders (particularly for electrical components and automobile radiators); metal alloys (including brass, bronze, and certain types of steel); plastics; leaded glass; ceramic glazes; ammunition; antique-molded or cast ornaments; and shielding used as protection from radiation sources. In the past, lead was added to residential paints and gasoline, and it has been used in plumbing for centuries. Small amounts of lead also may be emitted from the burning of fossil fuels.

Since the elimination of leaded gasoline in the United States and the removal of lead from solder in canned food containers, adult lead exposures tend to be limited to certain occupational and recreational sources. For children, the major sources of exposure are from deteriorated lead-based paint and the resulting dust and soil contamination. However, less common sources of exposure still exist, including lead-glazed ceramic pottery; pewter utensils and drinking vessels; plumbing systems with lead-soldered joints or lead pipes; lead-based painted surfaces undergoing renovation or demolition; lead-containing folk remedies; bullet fragments retained in human tissue; lead-contaminated

## Table 16. Lead in blood

Geometric mean and selected percentiles of blood concentrations (in µg/dL) for the U.S. population aged 1 year and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 1 and older** | 99-00 | **1.66** (1.60-1.72) | **1.60** (1.50-1.60) | **2.40** (2.30-2.60) | **3.80** (3.60-3.90) | **4.90** (4.60-5.30) | 7970 |
| | 01-02 | **1.45** (1.39-1.51) | **1.40** (1.30-1.40) | **2.20** (2.10-2.20) | **3.40** (3.10-3.50) | **4.40** (4.20-4.70) | 8945 |
| **Age group** | | | | | | | |
| 1-5 years | 99-00 | **2.23** (1.96-2.53) | **2.20** (1.90-2.50) | **3.30** (2.80-3.80) | **4.80** (4.00-6.60) | **7.00** (6.10-8.30) | 723 |
| | 01-02 | **1.70** (1.55-1.87) | **1.50** (1.40-1.70) | **2.50** (2.20-2.80) | **4.10** (3.40-5.00) | **5.80** (4.70-6.90) | 898 |
| 6-11 years | 99-00 | **1.51** (1.36-1.66) | **1.30** (1.20-1.50) | **2.00** (1.70-2.40) | **3.30** (2.70-3.60) | **4.50** (3.40-6.20) | 905 |
| | 01-02 | **1.25** (1.14-1.36) | **1.10** (1.00-1.30) | **1.60** (1.50-1.80) | **2.70** (2.40-3.00) | **3.70** (3.00-4.70) | 1044 |
| 12-19 years | 99-00 | **1.10** (1.04-1.17) | **1.00** (.900-1.10) | **1.40** (1.30-1.60) | **2.30** (2.10-2.30) | **2.80** (2.60-3.00) | 2135 |
| | 01-02 | **.942** (.899-.986) | **.800** (.800-.900) | **1.20** (1.20-1.30) | **1.90** (1.80-2.00) | **2.70** (2.30-2.90) | 2231 |
| 20 years and older | 99-00 | **1.75** (1.68-1.81) | **1.70** (1.60-1.70) | **2.50** (2.50-2.60) | **3.90** (3.70-4.00) | **5.20** (4.80-5.50) | 4207 |
| | 01-02 | **1.56** (1.49-1.62) | **1.60** (1.50-1.60) | **2.20** (2.20-2.30) | **3.60** (3.30-3.70) | **4.60** (4.20-4.90) | 4772 |
| **Gender** | | | | | | | |
| Males | 99-00 | **2.01** (1.93-2.09) | **1.80** (1.80-1.90) | **2.90** (2.80-3.00) | **4.40** (4.10-4.80) | **6.00** (5.40-6.40) | 3913 |
| | 01-02 | **1.78** (1.71-1.86) | **1.70** (1.70-1.80) | **2.70** (2.50-2.80) | **3.90** (3.70-4.10) | **5.30** (5.00-5.50) | 4339 |
| Females | 99-00 | **1.37** (1.32-1.43) | **1.30** (1.20-1.30) | **1.90** (1.90-2.10) | **3.00** (2.90-3.20) | **4.00** (3.70-4.20) | 4057 |
| | 01-02 | **1.19** (1.14-1.25) | **1.10** (1.10-1.20) | **1.80** (1.70-1.80) | **2.60** (2.40-2.70) | **3.60** (3.00-3.80) | 4606 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **1.83** (1.75-1.91) | **1.80** (1.60-1.80) | **2.70** (2.60-2.90) | **4.20** (3.90-4.50) | **5.80** (5.10-6.60) | 2742 |
| | 01-02 | **1.46** (1.34-1.60) | **1.50** (1.30-1.60) | **2.20** (2.00-2.60) | **3.60** (3.30-4.00) | **5.40** (4.40-6.60) | 2268 |
| Non-Hispanic blacks | 99-00 | **1.87** (1.75-2.00) | **1.70** (1.60-1.90) | **2.80** (2.50-2.90) | **4.20** (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) | **2.50** (2.30-2.80) | **4.20** (3.80-4.60) | **5.70** (5.30-6.50) | 2219 |
| Non-Hispanic whites | 99-00 | **1.62** (1.55-1.69) | **1.60** (1.50-1.60) | **2.40** (2.30-2.40) | **3.60** (3.40-3.70) | **5.00** (4.40-5.70) | 2716 |
| | 01-02 | **1.43** (1.37-1.48) | **1.40** (1.30-1.40) | **2.10** (2.10-2.20) | **3.10** (3.00-3.40) | **4.10** (3.90-4.50) | 3806 |

dust in indoor firing ranges; and contact with soil, dust, or water contaminated by active or inactive mining or smelting operations. Children may also be exposed to lead brought into the home on the work clothes of adults whose work involves lead.

Following inhalation of fine lead particulate or fume or ingestion of soluble lead compounds, absorbed lead is bound to erythrocytes and is distributed initially to multiple soft tissues, including the brain, kidneys, bone marrow, and gonads, and to a slower extent to the subperiosteal surface and matrix of bone. Lead also undergoes transplacental transport and poses a potential hazard to the fetus. The kinetics of lead clearance from the body are characterized by a multi-compartmental model, predominantly composed of the blood and soft tissues, with a half-life of 1 to 2 months, and 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, and scant amounts through sweat, hair, and nails (Leggett,

1993; O'Flaherty, 1993). The fraction of absorbed lead not undergoing prompt excretion, which is approximately half of the absorbed lead, may be incorporated into bone, the site of about 90% of the body lead burden in most adults.

Lead exerts multisystemic toxic effects through a variety of mechanisms, including interference in the function of essential cations such as calcium, zinc, and iron; inhibition of certain enzymes; binding to ion channels and regulatory proteins; generation of reactive oxygen species; and alteration in gene expression. Large amounts of lead in the body can cause clinical anemia, kidney injury, abdominal pain, seizures, encephalopathy, and paralysis. An increased prevalence of anemia has been observed with blood lead levels (BLLs) in excess of 25 µg/dL in children (Schwartz et al., 1990), or higher than 50 µg/dL in adults (Lilis et al., 1977). Kidney toxicity associated with chronic high-dose lead exposure includes interstitial and peritubular fibrosis, but low-level environmental lead exposure also can be associated with

### Table 17. Lead in urine

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.766** (.708-.828) | **.800** (.700-.800) | **1.30** (1.30-1.40) | **2.10** (2.00-2.30) | **2.90** (2.60-3.20) | 2465 |
| | 01-02 | **.677** (.637-.718) | **.600** (.600-.700) | **1.20** (1.10-1.20) | **2.00** (1.80-2.00) | **2.60** (2.50-2.80) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **1.07** (.955-1.20) | **1.00** (.900-1.20) | **1.50** (1.40-1.60) | **2.40** (1.80-3.00) | **3.40** (2.40-5.00) | 340 |
| | 01-02 | **.753** (.661-.857) | **.800** (.600-.800) | **1.20** (1.00-1.30) | **2.00** (1.60-2.40) | **2.60** (2.10-3.60) | 368 |
| 12-19 years | 99-00 | **.659** (.579-.749) | **.600** (.500-.800) | **1.10** (.900-1.20) | **1.70** (1.40-2.10) | **2.20** (1.90-2.50) | 719 |
| | 01-02 | **.564** (.526-.605) | **.600** (.500-.600) | **.900** (.800-1.10) | **1.50** (1.40-1.70) | **1.90** (1.70-2.10) | 762 |
| 20 years and older | 99-00 | **.752** (.691-.818) | **.700** (.700-.800) | **1.40** (1.20-1.50) | **2.10** (1.90-2.30) | **2.90** (2.50-3.20) | 1406 |
| | 01-02 | **.688** (.641-.738) | **.700** (.600-.700) | **1.20** (1.10-1.20) | **1.90** (1.80-2.10) | **2.80** (2.50-2.90) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.923** (.822-1.04) | **.900** (.800-.900) | **1.60** (1.40-1.80) | **2.40** (2.20-2.90) | **3.40** (2.90-3.70) | 1227 |
| | 01-02 | **.808** (.757-.862) | **.700** (.700-.800) | **1.30** (1.30-1.50) | **2.40** (2.20-2.70) | **3.20** (2.90-3.50) | 1335 |
| Females | 99-00 | **.642** (.589-.701) | **.600** (.600-.700) | **1.20** (1.10-1.30) | **1.90** (1.60-2.10) | **2.40** (2.00-2.90) | 1238 |
| | 01-02 | **.573** (.535-.613) | **.500** (.500-.600) | **1.00** (1.00-1.10) | **1.50** (1.40-1.70) | **2.20** (1.90-2.40) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **1.02** (.915-1.13) | **1.00** (.900-1.20) | **1.70** (1.60-1.90) | **2.80** (2.50-3.40) | **4.10** (3.10-5.40) | 884 |
| | 01-02 | **.833** (.745-.931) | **.900** (.700-1.00) | **1.50** (1.20-1.70) | **2.40** (2.00-2.90) | **3.20** (2.70-3.70) | 683 |
| Non-Hispanic blacks | 99-00 | **1.11** (1.00-1.23) | **1.10** (1.00-1.20) | **1.90** (1.50-2.00) | **2.90** (2.40-3.50) | **4.20** (3.30-5.70) | 568 |
| | 01-02 | **.940** (.833-1.06) | **.900** (.800-.900) | **1.50** (1.30-1.80) | **2.60** (2.00-3.20) | **3.70** (2.90-4.80) | 667 |
| Non-Hispanic whites | 99-00 | **.695** (.625-.773) | **.700** (.600-.700) | **1.30** (1.10-1.40) | **1.90** (1.70-2.20) | **2.60** (2.30-3.00) | 822 |
| | 01-02 | **.610** (.572-.651) | **.600** (.600-.700) | **1.00** (1.00-1.10) | **1.80** (1.70-2.00) | **2.40** (2.10-2.50) | 1132 |

small decrements in renal function (Payton et al., 1994; Kim et al., 1996; Muntner et al., 2003).

Low-level environmental lead exposure has been associated with subclinical decrements in neurocognitive function in young children and elevated blood pressure in adults. Although in 1991 the Centers for Disease Control and Prevention (CDC) established 10 µg/dL as a blood lead concentration of concern in children, no threshold for lead's effects has yet been identified (National Research Council, 1993). Recent studies have suggested possible neurodevelopmental effects at blood lead concentrations of less than 10 µg/dL (Lanphear et al., 2000; Canfield et al., 2003); further assessment is ongoing. In adults, subtle, nonspecific neurocognitive effects may occur at BLLs as low as 20-60 µg/dL (Mantere et al., 1984; Schwartz et al., 2001), with overt encephalopathy, seizures, and peripheral neuropathy at higher levels (e.g., levels greater than 100 µg/dL). Results of studies of adults with occupational or environmental lead exposure have shown consistent

associations between increased BLLs and increased blood pressure (Schwartz, 1995; Staessen et al., 1995; Nash et al., 2003) and associations between increased bone lead concentrations and blood pressure (Hu et al., 1996; Korrick et al., 1999).

The potential adverse effects of lead on reproduction are an area of ongoing research and may include increased spontaneous abortion in women (Borja-Aburto et al., 1999) and problems with sperm formation in men (Alexander et al., 1996; Telisman et al., 2000). The International Agency for Research on Cancer (IARC) considers lead as a possible human carcinogen, and the National Toxicology Program (NTP) considers lead and its compounds as reasonably anticipated to be human carcinogens (NTP, 2005), but further study is needed on the relation between lead exposure and cancer in people (Jemal et al., 2002).

## Table 18. Lead in urine (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.721** (.700-.742) | **.700** (.677-.725) | **1.11** (1.06-1.15) | **1.70** (1.62-1.85) | **2.37** (2.21-2.76) | 2465 |
| | 01-02 | **.639** (.603-.677) | **.634** (.586-.676) | **1.03** (.962-1.08) | **1.52** (1.42-1.60) | **2.03** (1.89-2.22) | 2689 |
| **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** (.798-.933) | **1.26** (1.12-1.43) | **2.33** (1.59-3.64) | **3.64** (1.83-5.56) | 368 |
| 12-19 years | 99-00 | **.496** (.460-.535) | **.469** (.408-.508) | **.702** (.655-.828) | **1.10** (.981-1.28) | **1.65** (1.15-2.78) | 719 |
| | 01-02 | **.404** (.380-.428) | **.373** (.342-.400) | **.602** (.541-.702) | **.990** (.882-1.18) | **1.41** (1.07-1.63) | 762 |
| 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** (2.11-2.62) | 1406 |
| | 01-02 | **.658** (.617-.703) | **.649** (.608-.702) | **1.04** (.992-1.11) | **1.51** (1.40-1.61) | **2.00** (1.85-2.19) | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.720** (.679-.763) | **.693** (.645-.734) | **1.10** (.991-1.22) | **1.68** (1.50-2.09) | **2.43** (2.15-3.03) | 1227 |
| | 01-02 | **.639** (.607-.673) | **.638** (.586-.684) | **1.01** (.957-1.08) | **1.55** (1.41-1.61) | **2.06** (1.88-2.43) | 1334 |
| Females | 99-00 | **.722** (.681-.765) | **.706** (.667-.746) | **1.11** (1.05-1.16) | **1.74** (1.50-2.02) | **2.38** (2.03-2.88) | 1238 |
| | 01-02 | **.639** (.594-.688) | **.625** (.571-.670) | **1.03** (.938-1.11) | **1.50** (1.39-1.61) | **1.98** (1.85-2.15) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.940** (.876-1.01) | **.882** (.796-1.02) | **1.43** (1.36-1.56) | **2.38** (2.08-2.77) | **3.31** (2.78-4.18) | 884 |
| | 01-02 | **.810** (.731-.898) | **.769** (.702-.893) | **1.28** (1.09-1.44) | **2.05** (1.75-2.50) | **2.78** (2.55-3.33) | 682 |
| Non-Hispanic blacks | 99-00 | **.722** (.659-.790) | **.667** (.583-.753) | **1.11** (.988-1.20) | **1.98** (1.56-2.51) | **2.83** (2.20-3.88) | 568 |
| | 01-02 | **.644** (.559-.742) | **.606** (.510-.710) | **.962** (.853-1.19) | **1.79** (1.36-2.33) | **2.75** (2.04-3.98) | 667 |
| 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** (.930-1.06) | **1.46** (1.37-1.52) | **1.88** (1.61-2.00) | 1132 |

**Interpreting Levels of Lead in Blood and Urine Reported in the Tables**

Levels of lead in blood were measured in all participants aged 1 year and older and urine lead levels were measured in a sample of people aged 6 years and older. Participants were selected to be a representative sample of the U.S. population. Blood lead measurement is the preferred method of evaluating lead exposure and its health effects in people. BLLs are contributed to by both recent intake and an equilibration with stored lead in other tissues, particularly in the skeleton. Urinary lead measurements are more variable than blood lead levels for a given individual.

The U.S. adult population has similar or slightly lower BLLs than adults in other developed nations. A general population survey of 4,646 adults in Germany in 1998 reported a geometric mean blood lead concentration of 3.07 µg/dL (Becker et al., 2002), a value nearly twice that found for U.S. adults in the 2001-2002 NHANES sample. A general population survey of 1,164 adults in Italy in 2000 found blood lead values slightly more than double those reported for U.S. adults in the 2001-2002 NHANES sample (Apostoli et al., 2002*a*).

In 1991, CDC designated 10 µg/dL as the blood lead level of concern in children, a level associated with the risk for subtle neurodevelopmental impairments. For children 1- 5 years old sampled over the four year period 1999-2002, the geometric mean BLL was 1.9 µg/dL (1.8-2.1), with 1.6% (1.1-2.3) of the children having BLLs greater than or equal to 10 µg/dL. Data from NHANES III, (phase 2, 1991-1994) showed that 4.4% of children aged 1-5 years had BLLs greater than or equal to 10 µg/dL, and the geometric mean BLL for children aged 1-5 years was 2.7 µg/dL (Pirkle et al., 1998). State childhood blood lead surveillance systems reported blood lead results for 2.4 million children to CDC in 2001. Of these children, 3.09% had a confirmed BLL of greater than or equal to 10 µg/dL (CDC, 2003*a*). Among a predominantly non-white population of U.S. children aged 0 to 17 years who were screened at an urban medical center in Washington, D.C. in 2001 and 2002, the geometric mean BLL in males was 3.2 µg/dL (n = 5,584) and 3.0 µg/dL in females (n = 5,562) (Soldin et al., 2003). These levels are higher than levels in similar age groups in the 2001-2002 NHANES sample and may reflect a higher prevalence of elevated BLLs that occur among children who 1) are non-Hispanic black and Mexican American; 2) live in urban settings; 3) are from lower socioeconomic groups; 4) are immigrants, refugees, or 5) reside in housing built before 1950 (CDC, 2003*a*; CDC, 2002; Geltman et al., 2001). In places where leaded gasoline is still used, such as in

Bangladesh, BLLs among school children are similar to BLLs measured in the United States before lead was removed from gasoline (i.e., a mean BLL of 15.0 µg/dL and 87.4% of children with levels in excess of 10 µg/dL [Kaiser et al., 2001]).

The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) requires monitoring of blood lead levels when occupational exposure to airborne levels of lead exceeds the established action level of greater than 30 micrograms per cubic meter of air (OSHA, 29 CFR 1910.1025). First established in the late 1970s, OSHA regulations have required medical removal of workers from workplace lead exposure when blood lead concentrations exceed 50 µg/dL or at lower levels per a physician's discretion. The American Conference of Governmental Industrial Hygienists (ACGIH, 2001) established a Biological Exposure Index (BEI) for inorganic lead in 1995 which recommended that BLL in workers remain less than 30 µg/dL. Levels for adults in the NHANES 1999-2000 and 2001-2002 samples are generally below these worker thresholds (four adult NHANES participants were above 30 µg/dL).

**Comparing Adjusted Geometric Means**

Geometric mean BLLs for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, and log serum cotinine (data not shown). In NHANES 2001-2002, adjusted geometric mean BLLs were higher in children aged 1-5 years than in children aged 6-11 years, and both these age groups had higher levels than did those aged 12-19 years. BLLs in adults aged 20 years and older were higher than BLLs in the group aged 12-19 years. BLLs for males were higher than those for females. Non-Hispanic whites had lower BLLs than non-Hispanic blacks.

For urinary lead in NHANES 2001-2002, adjusted geometric mean levels of urinary lead in the group aged 6-11 years were higher than either the group aged 12-19 years or the group aged 20 years and older. The group aged 20 years and older had higher levels than the group aged 12-19 years. Mexican Americans had higher urinary levels than either non-Hispanic blacks or whites. Non-Hispanic blacks had higher levels than non-Hispanic whites. Males had slightly higher levels than females.

It is unknown whether these differences associated with age, gender or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight. For instance, to account for the decreasing BLLs observed with increasing ages during childhood, several explanations are possible, including

decreasing exposure, dilution of lead by growth of body mass, or changing equilibria with bone turnover.

These blood and urine levels of lead provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of lead than are found in the general population. These data will also help scientists plan and conduct research about exposure to lead and health effects.

## Figure 6. Lead in blood

Selected percentiles with 95% confidence intervals of blood concentrations (in µg/dL) for the U.S. population aged 1 year and older, National Health and Nutrition Examination Survey, 1999-2002.
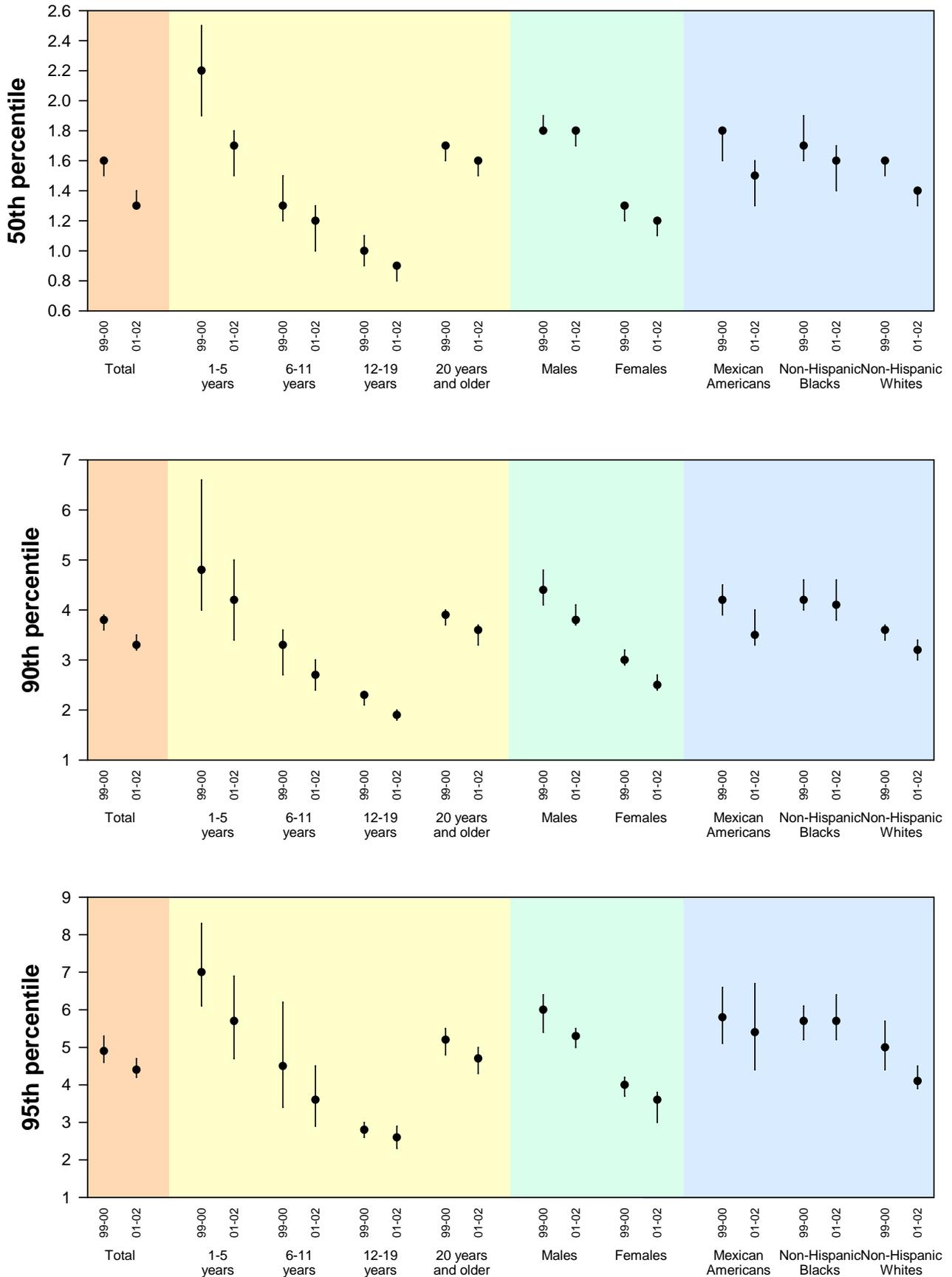
### Figure 7. Lead in urine (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
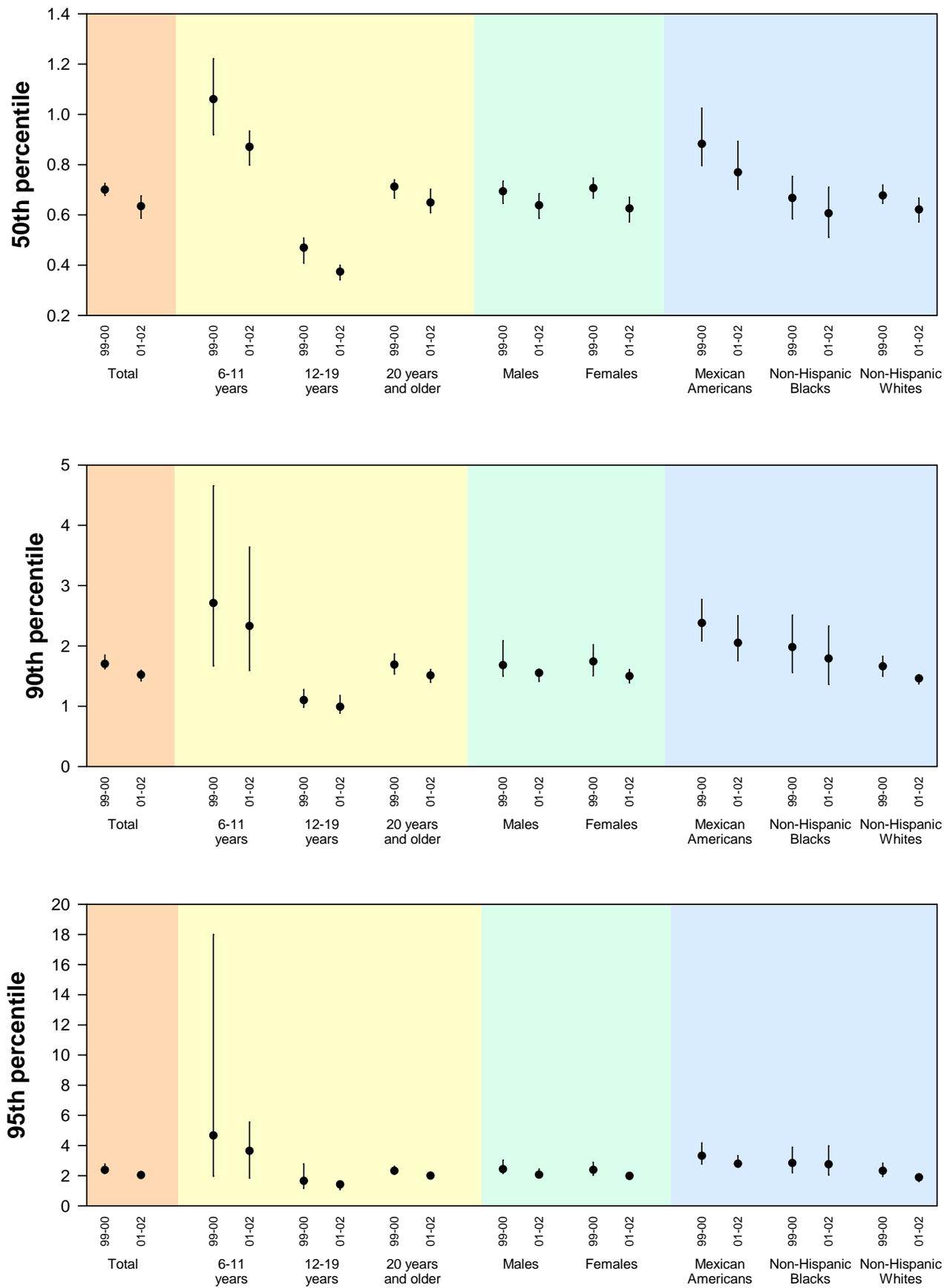
# Mercury

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. 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 the production of batteries and pigments. Pharmaceutical applications of mercury have been declining, although certain organomercury compounds are still used as preservatives (e.g., thimerosal, phenylmercuric acetate) or topical antiseptics (e.g.,

merbromin). Some cosmetic skin creams from countries other than the U.S. may contain mercury. Folk medicines may contain mercury compounds, and elemental mercury is used ritually 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. Through biogeochemical cycling, some atmospheric elemental mercury is deposited on land and water. In addition, water can be contaminated by the direct release of elemental and inorganic mercury from industrial processes. Metabolism of mercury by microorganisms in sediments creates methyl mercury, an organomercurial compound, which can bioaccumulate in terrestrial and especially aquatic 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. Using the 1999-2000 NHANES data, it was estimated that women 16 to 49 years of age ingest a geometric

## Table 19. Mercury in blood

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) | | | | Sample size |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | | | 50th | 75th | 90th | 95th | |
| **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 |

## Table 20. Mercury in urine

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) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **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 |

mean of 1.22 micrograms of mercury per day from fish/seafood (approximately 85% as methyl mercury) (Mahaffey et al., 2004). Inhalation of mercury volatilized from dental amalgam is another major source of mercury exposure in the general population and is estimated to result in a daily intake of 1-5 µg per day (U.S. DHHS, 1993). Accidental spills of elemental mercury, which create the potential for subsequent volatization and inhalation of mercury vapor, have often required public health intervention (Zeitz et al., 2002).

The kinetics of the different forms of mercury vary considerably. Elemental mercury, absorbed mainly through inhalation of volatilized vapor, undergoes distribution to most tissues, with the highest concentrations occurring in the kidney (Hursh et al., 1980; Barregard et al., 1999). After absorption of elemental mercury, blood concentrations decline initially with a rapid half-life of approximately 1-3 days followed by a slower half-life of approximately 1 week to 3 weeks (Barregard et al., 1992; Sandborgh-Englund et al., 1998). The slow-phase half-life may be several weeks longer in people 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 mercury 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).

About 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 (Sherlock et al., 1984; Smith et al., 1994; Smith and Farris, 1996). After exposure to methyl mercury, greater than two-thirds of the mercury is excreted via the feces, with a relatively minor amount eliminated as inorganic mercury in the urine (Smith et al., 1994; Smith and Farris, 1996). Small fractions of inorganic mercury and methyl mercury are incorporated into hair (Suzuki et al., 1993), which has been used in epidemiologic studies as a biomarker of exposure to methyl mercury (McDowell et al., 2004).

## Table 21. Mercury in urine (creatinine corrected)

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) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **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 |

Inorganic mercury and methyl mercury are also distributed into human breast milk, although the process may be more efficient for inorganic mercury (Grandjean et al., 1995; Oskarsson et al., 1996). Transplacental transport of methyl mercury and elemental mercury has been demonstrated in animal models. In a recent human study, concentrations of mercury in umbilical cord blood were correlated with mercury concentrations in maternal hair, maternal fish/seafood consumption, and maternal dental amalgam (Bjornberg et al., 2003). A recent meta-analysis of human studies of the ratio of mercury in umbilical cord blood to maternal blood produced an estimate of 1.7 (Stern and Smith, 2003).

The health effects of mercury are diverse and can depend on the form of the mercury to which a person is exposed and the severity and length 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). Subclinical neurological effects of low-level occupational exposure to elemental mercury have been found in some investigations (Chapman et al., 1990; Bittner et al., 1998), but an impact of low-level environmental exposure, such as that resulting from

dental amalgam, has not been established (Factor-Litvak et al., 2003; Bates et al., 2004a).

Exposure to inorganic mercury usually occurs by ingestion. The most prominent effect is on the kidneys, where mercury accumulates, and leads to tubular necrosis. In addition, there may be an irritant or corrosive effect on the gastrointestinal tract (Sanchez-Sicilia et al., 1963). Occupational exposure to elemental mercury vapor has been associated with subclinical effects on biomarkers of renal dysfunction (Cardenas et al., 1993). Acrodynia, a sporadic and predominantly pediatric syndrome in which the constellation of findings may include anorexia, insomnia, irritability, hypertension, maculopapular rash, pain in the extremities and pinkish discoloration of the hands and feet, has been associated with a variety of exposures to elemental mercury and inorganic mercury compounds (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. Methyl mercury has well-characterized adverse reproductive effects. High-level prenatal exposure may result in a constellation of developmental deficits that include mental retardation, cerebellar ataxia, dysarthria, limb deformities, altered physical growth, sensory impairments, and cerebral

palsy (National Research Council, 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 (National Research Council, 2000; Rice et al., 2003). Although recent  investigations have suggested a possible link between chronic ingestion of methyl mercury and an increased risk for myocardial infarction (Guallar et al., 2002; National Research Council, 2000), the existence of a causal relation is unresolved. Information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA's IRIS Web site at http://www.epa.gov/iris, the U.S. EPA's mercury homepage at http://www.epa.gov/mercury, and from ATSDR's Toxicological Profiles at http://www.atsdr.cdc. gov/toxprofiles.

**Interpreting Levels of Mercury in Blood and Urine Reported in the Tables**

Blood mercury levels were measured in a subsample of NHANES participants aged 1-5 years and in females aged 16-49 years. Participants were selected within the specified age range to be a representative sample of the U.S. population. The measurement of total blood mercury includes both inorganic and organic forms. In the general population, the total blood mercury concentration is due mostly to the dietary intake of organic forms, particularly of methyl mercury. Little organic mercury is excreted in the urine. Urinary mercury consists mostly of inorganic mercury (Cianciola et al., 1997; Kingman et al., 1998). These distinctions can assist in interpreting mercury blood levels in people. Total blood mercury levels are known to increase with greater fish consumption (Grandjean et al., 1995; Mahaffey and Mergler, 1998; Sanzo et al., 2001; Dewailly et al., 2001), and urine levels will increase with the number of teeth filled with mercury-containing amalgams (Becker et al., 2003).

The data in this *Report* are similar or slightly lower than levels found in other population studies. In Germany, for example, the geometric mean for blood mercury was 0.58 µg/L for 4,645 adults aged 18 to 69 years participating in a 1998 representative population survey (Becker et al., 2002). During the years 1996 through 1998, Benes et al. (2000) studied 1,216 blood donors in the Czech Republic (896 men and 320 women; average age 33 years) and 758 children (average age 9.9 years). The median concentration of blood mercury for adults was 0.78 µg/L and 0.46 µg/L for the juvenile population. A cohort of 1,127 U.S. men

(mean age 52.8 years, range 40 years to 78 years) with no occupational exposure to mercury, but who received dental care at military facilities during the mid to late 1990s, had an average blood mercury concentration of 2.55 µg/L (Kingman et al., 1998).

Blood mercury levels in both the 1999-2000 and 2001-2002 subsamples are below levels considered associated with known health effects. When blood mercury levels rise to about 100 µg/L following recent inorganic or elemental mercury poisoning, abnormal renal function tests may occur with low frequency. Total blood mercury levels in this *Report* were also well below levels established as occupational exposure guidelines. ACGIH recommends that the blood levels of inorganic mercury in workers not exceed 15 µg/L (six participants in the survey had higher levels, although these levels were unlikely to be due to inorganic forms of mercury). Information about the biological exposure indices (BEIs) is provided here for comparison, not to imply that the BEI is a safety level for general population exposure.

Clinically observable signs of ataxia and paresthesias occur with low frequency when blood mercury levels rise to about 100 µg/L following recent methyl mercury poisoning. However, the developing fetus may be the most susceptible to the effects of ongoing methyl mercury exposure (National Research Council, 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, 2000). *Report* data for the period 1999-2002 show that all women of childbearing age had levels below 58 µg/L, a concentration associated with neurologic effects in the fetus.  These data show that 5.7% of women of childbearing age had levels between 5.8 and 58 µg/L; that is, levels within a factor of 10 of those associated with neurological effects. Better defining safe levels of mercury in maternal blood is a priority area for additional research. EPA has set an oral reference dose (RfD, a daily dose considered to be safe) for methyl mercury of 0.1µg/kg/day, derived in part from this and other associated blood levels in outcome studies. A specific value for the blood mercury concentration that corresponds to the RfD has not been established (Rice, 2004).

Urinary mercury levels in recent German (Becker et al., 2003), Czech (Benes et al., 2002), and Italian (Apostoli et al., 2002*b*) adult population surveys were roughly similar to the values found for women in the 2001–2002 NHANES subsample. An expert-panel

report recently prepared for the U.S. Department of Health and Human Services (U.S. DHHS) 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 greater than or equal to 25-35 µg/L (Life Sciences Research Office, 2004). The ACGIH (2001) currently recommends that urinary inorganic mercury in workers not exceed 35 µg/gram of creatinine.

**Comparing Adjusted Geometric Means**

Geometric mean levels of blood mercury for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, creatinine, and log serum cotinine (data not shown). In NHANES 2001-2002, non-Hispanic black females aged 16-49 years had higher levels than non-Hispanic white and Mexican-American females aged 16-49 years. Non-Hispanic white females aged 16-49 years had higher levels than Mexican American females aged 16-49 years. It is unknown whether these differences associated with age or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

For urinary mercury levels, there were no differences of the adjusted geometric means among the three race/ethnicity groups.

Finding a measurable amount of mercury in blood or urine does not mean that the level of mercury causes an adverse health effect. These data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of mercury than are found in the general population. These data will also help scientists plan and conduct research about mercury exposure and health effects.

# Figure 8. Mercury in blood

Selected percentiles with 95% confidence intervals 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.
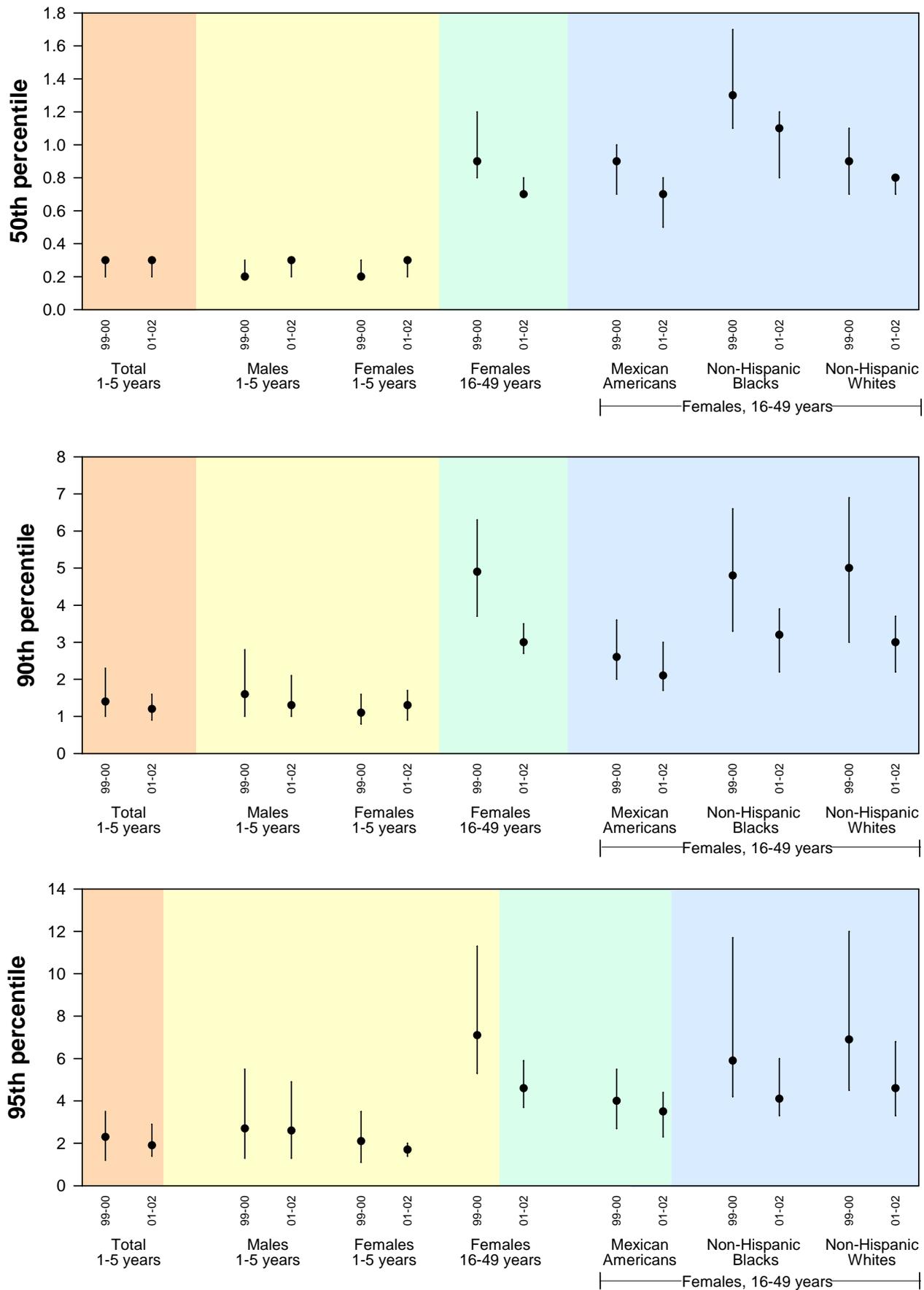
# Figure 9. Mercury in urine (creatinine corrected)

Selected percentiles with 95% confidence intervals 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.
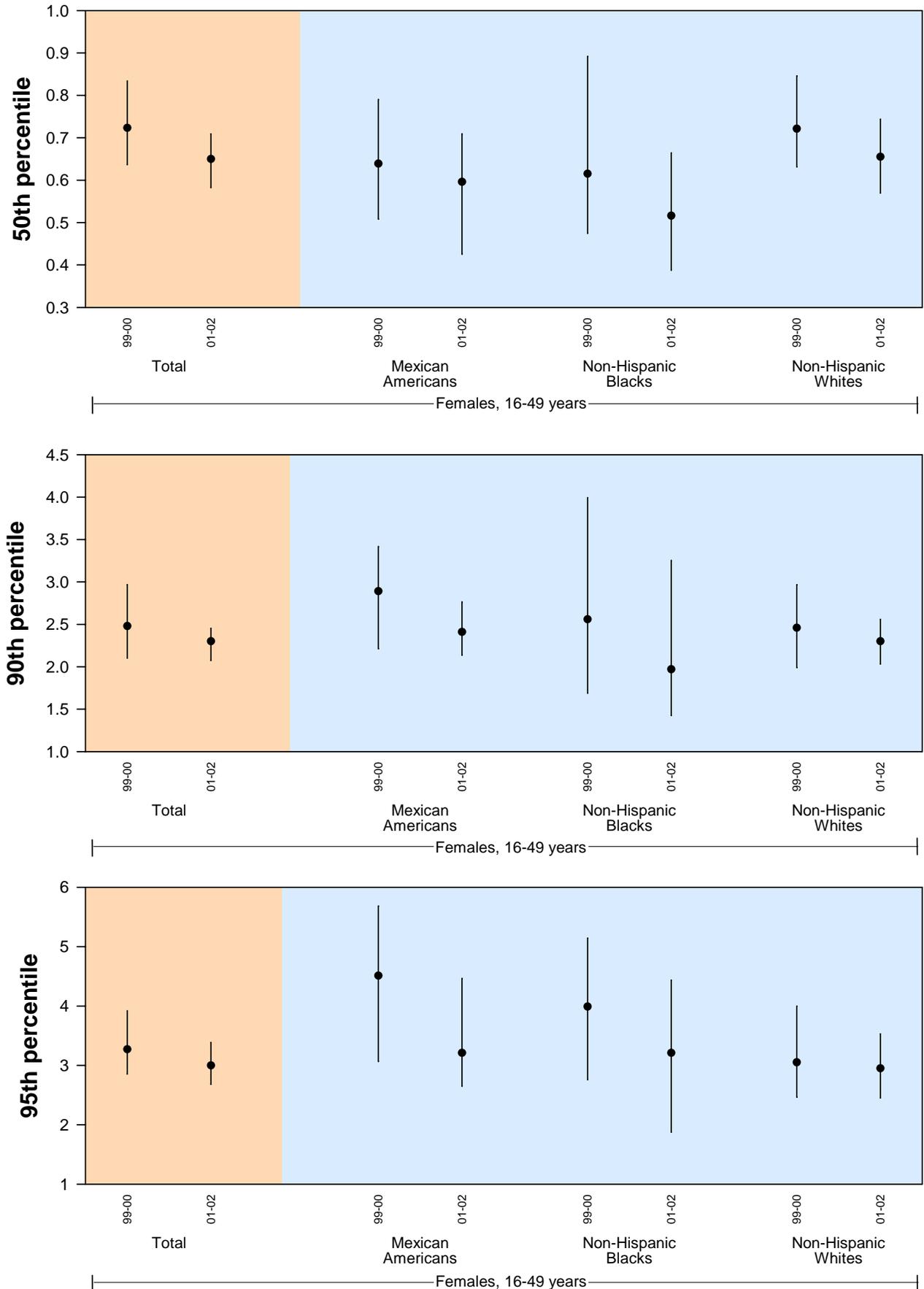
# Molybdenum

CAS No. 7439-98-7

## General Information

Elemental molybdenum is a silver-white, hard metal with many commercial uses, including the production of metal alloys. Compounds of molybdenum are used as corrosion inhibitors; hydrogenation catalysts; lubricants; alloys in steel; chemical reagents in hospital laboratories; and in pigments for ceramics, inks and paints.

Molybdenum is a nutritionally essential trace element and enters the body primarily from dietary sources. Molybdenum is a cofactor for a limited number of human enzymes, principally sulfite oxidase and xanthine oxidase (Kisker et al., 1997). The recommended dietary allowance for adult men and women is 45 µg/day (Institute of Medicine, 2001), and the average dietary daily intake of molybdenum is approximately 100 µg/day (WHO, 1996; Institute of Medicine, 2001). Molybdenum

occurs in natural waters and may be present in concentrations of several hundred micrograms per liter or higher in ground and surface water in the vicinity of mining operations or ore deposits. In industry, dust and other fine particles produced during the refining or shaping of molybdenum or molybdenum-containing alloys are sources of exposure.

Gastrointestinal absorption of molybdenum averages 88-93% for dietary intakes of 22 to 1490 µg/day. Excretion occurs predominantly via the kidney, which exerts homestatic regulation over molybdenum balance. At a daily oral molybdenum dose of 24 µg, urinary excretion over a six day period was 18% of the ingested dose, but at daily oral doses of 95 µg and 428 µg, urinary excretion over a six day period rose to 50% and 67% of the ingested dose, respectively (Turnlund et al., 1995).

## Table 22. Molybdenum

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **45.9** (40.1-52.6) | **50.7** (44.6-58.4) | **84.9** (78.7-92.3) | **134** (125-146) | **178** (154-216) | 2257 |
| | 01-02 | **45.0** (42.1-48.0) | **52.4** (48.9-55.5) | **83.3** (79.1-88.5) | **124** (117-130) | **165** (145-176) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **78.2** (61.0-100) | **83.4** (67.7-105) | **126** (106-147) | **174** (147-242) | **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 |
| 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) | **183** (146-216) | 648 |
| | 01-02 | **60.6** (55.5-66.2) | **65.7** (58.7-73.1) | **96.9** (91.8-108) | **145** (129-159) | **179** (155-227) | 762 |
| 20 years and older | 99-00 | **41.7** (36.7-47.4) | **46.5** (40.5-52.3) | **76.7** (73.4-82.2) | **125** (114-134) | **167** (143-206) | 1299 |
| | 01-02 | **41.1** (38.3-44.1) | **47.4** (43.7-51.2) | **79.0** (71.9-83.6) | **114** (103-124) | **150** (130-166) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **52.7** (45.7-60.7) | **57.4** (48.5-68.4) | **93.2** (83.8-106) | **150** (128-187) | **213** (161-278) | 1121 |
| | 01-02 | **51.0** (46.6-55.7) | **56.9** (51.8-62.6) | **88.5** (81.6-96.5) | **130** (120-141) | **169** (145-194) | 1335 |
| Females | 99-00 | **40.4** (34.8-46.8) | **45.5** (40.4-52.0) | **77.2** (71.0-85.7) | **118** (105-138) | **154** (132-180) | 1136 |
| | 01-02 | **39.9** (37.2-42.9) | **45.7** (42.7-49.0) | **78.4** (72.6-82.9) | **114** (104-128) | **158** (130-177) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **47.0** (42.1-52.4) | **53.2** (49.0-59.0) | **80.3** (73.7-91.7) | **120** (103-139) | **152** (120-217) | 780 |
| | 01-02 | **49.3** (46.5-52.3) | **55.7** (50.4-61.0) | **86.3** (80.8-94.1) | **133** (113-155) | **177** (142-207) | 683 |
| Non-Hispanic blacks | 99-00 | **57.7** (51.0-65.2) | **61.8** (55.0-71.5) | **97.7** (85.0-110) | **151** (126-188) | **202** (150-274) | 546 |
| | 01-02 | **53.2** (49.9-56.7) | **60.3** (54.2-63.1) | **89.9** (81.0-101) | **130** (121-147) | **166** (147-170) | 667 |
| Non-Hispanic whites | 99-00 | **44.5** (37.0-53.4) | **48.5** (41.1-59.8) | **85.0** (76.7-95.9) | **135** (119-154) | **178** (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 |

Molybdenum is generally considered to be of low toxicity to people, and clinical or epidemiological evidence of adverse effects is limited. Chronic exposure to high levels may possibly result in higher serum uric acid levels and 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 (Institute of Medicine, 2001). A long term inhalation bioassay of molybdenum trioxide in mice yielded "some evidence" of carcinogenicity (NTP, 1997). A recent case-control study suggested a possible link between occupational exposure to molybdenum and lung cancer (Droste et al., 1999) but the available epidemiological data are scant and molybdenum has not been systematically evaluated for carcinogenicity by U.S. EPA or IARC.

**Interpreting Levels of Urinary Molybdenum Reported in the Tables**

Urinary molybdenum levels were measured in a subsample of NHANES participants aged 6 years and older. Subsamples were randomly selected within the specified age range to be a representative sample of the U.S. population. Because molybdenum is an essential element for good health, intake and loss in the urine is expected. The levels documented for adults in the NHANES 2001-2002 subsample are broadly comparable to levels reported for adults in recent smaller European population surveys (Minoia et al., 2002; White and Sabbioni, 1998; Iversen et al., 1998). Among infants, urinary molybdenum concentrations may be slightly lower than other age groups (Sievers et al., 2001).

### Table 23. Moylbdenum (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **43.2** (40.0-46.6) | **41.5** (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 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **85.9** (73.7-100) | **78.9** (71.6-88.4) | **122** (107-133) | **173** (130-243) | **213** (154-1040) | 310 |
| | 01-02 | **77.2** (73.1-81.5) | **77.5** (71.8-84.5) | **109** (99.4-120) | **154** (129-170) | **185** (165-219) | 368 |
| 12-19 years | 99-00 | **41.9** (39.3-44.6) | **40.5** (37.7-44.4) | **57.3** (51.5-62.5) | **85.0** (67.4-107) | **109** (78.4-185) | 648 |
| | 01-02 | **43.4** (40.8-46.1) | **44.1** (40.8-47.2) | **60.6** (57.6-63.7) | **85.5** (79.7-93.8) | **106** (94.8-118) | 762 |
| 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) | **120** (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) | **122** (109-139) | 1559 |
| **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) | **60.4** (54.8-66.3) | **91.3** (83.4-106) | **123** (107-155) | 1334 |
| Females | 99-00 | **45.5** (41.5-50.0) | **43.7** (39.5-48.8) | **64.4** (59.5-70.5) | **111** (95.2-121) | **149** (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 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **42.9** (40.6-45.4) | **43.2** (40.9-45.6) | **61.6** (57.2-65.5) | **89.0** (80.0-103) | **115** (93.7-137) | 780 |
| | 01-02 | **48.1** (44.3-52.2) | **48.4** (44.8-52.3) | **71.5** (66.4-76.0) | **103** (90.0-120) | **129** (109-155) | 682 |
| Non-Hispanic blacks | 99-00 | **37.2** (33.4-41.6) | **37.0** (33.0-41.2) | **55.9** (49.6-63.3) | **88.2** (69.1-112) | **117** (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 |
| 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 |

**Comparing Adjusted Geometric Means**

Geometric mean levels of urinary molybdenum for the
demographic groups were compared after adjusting for
the covariates of race/ethnicity, age, gender, creatinine,
and log serum cotinine (data not shown). In NHANES
2001-2002, adjusted geometric mean levels of urinary
molybdenum were higher for children aged 6-11 years
than for people aged 12-19 years or aged 20 years and
older. The group aged 12-19 years had higher levels than
the group aged 20 years and older. Non-Hispanic blacks
had slightly lower levels than non-Hispanic whites and
Mexican Amercians. It is unknown whether these
differences associated with age or race/ethnicity
represent differences in exposure, pharmacokinetics, or
the relationship of dose per body weight.

These urinary molybdenum data provide physicians with
a reference range so that they can determine whether
people have been exposed to higher levels of
molybdenum than are found in the general population.
These data will also help scientists plan and conduct
research about molybdenum exposure and health effects.

## Figure 10. Molybdenum (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
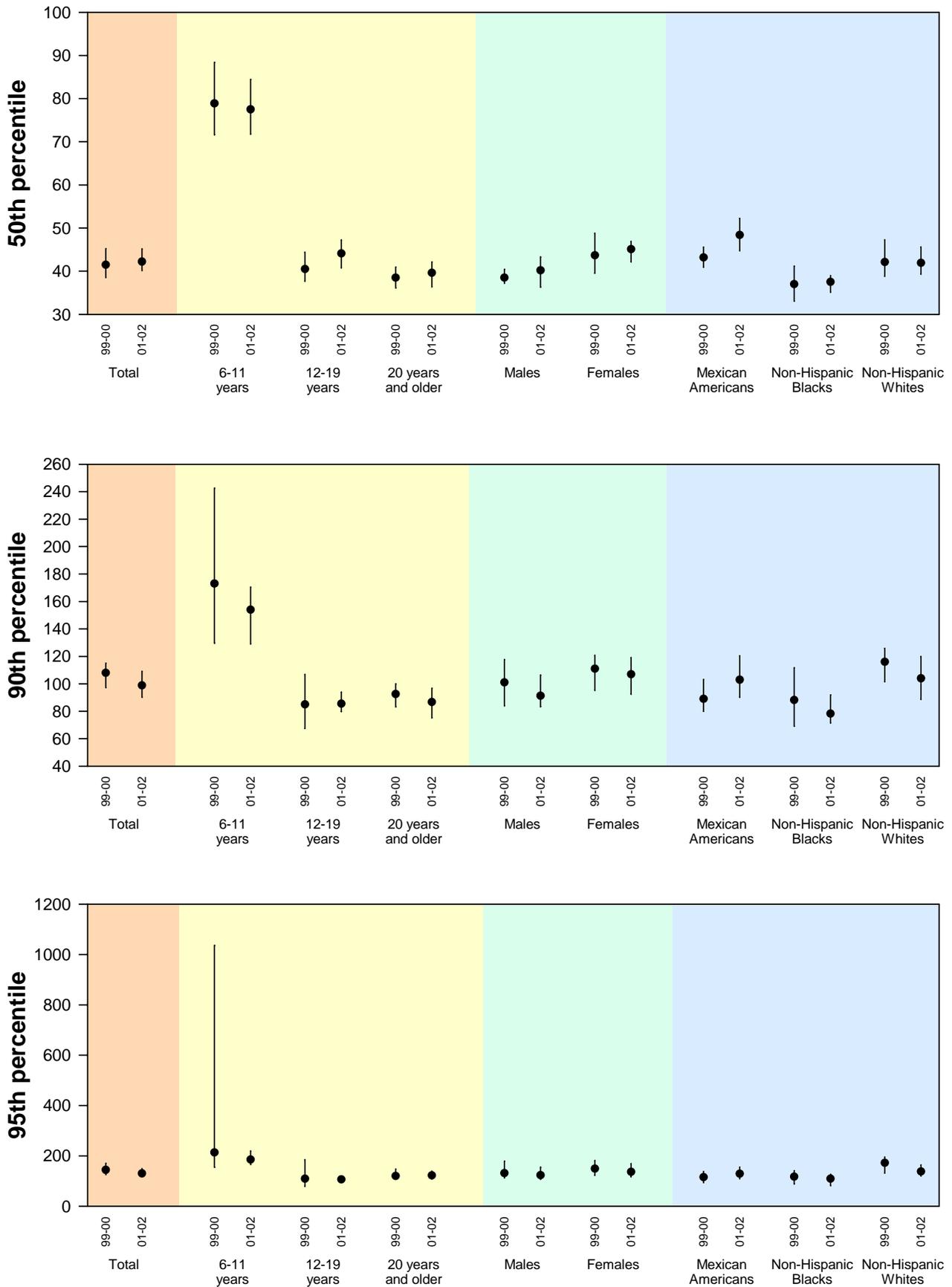
# Platinum
CAS No. 7440-06-4

## General Information

Platinum is a silver-gray, lustrous metal found naturally in extremely low amounts in the earth's crust and typically is associated with sulfide-ore bodies of nickel, copper, and iron. Important properties of platinum are its resistance to corrosion, strength at high temperatures, and high catalytic activity.

Platinum compounds are also used in electrodes and jewelry, as oxidation catalysts in chemical manufacturing, in thick-film circuits printed on ceramic substrates, 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 the control of automobile-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 have been associated with nearby roadways due to vehicular emissions (Farago et al., 1998), although the ambient air concentrations of platinum associated with its use in automotive engine catalytic converters are estimated to be 10,000 times lower than occupational exposure limits.

The acute and chronic toxic effects of exposure to platinum are highly dependent on the type of compound (e.g., metallic, inorganic salt, or organometallic), the route of exposure (e.g., intravenous (medicinal use), inhalational, cutaneous, oral), and duration of exposure. Platinum metal is considered biologically inert, whereas platinum compounds (e.g., salts) can cause acute and chronic irritant and immune-mediated hypersensitivity reactions, such as bronchitis and asthma following inhalational exposure. Also, contact dermatitis following

## Table 24. Platinum

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 2465 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 340 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 368 |
| 12-19 years | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 719 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 762 |
| 20 years and older | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1406 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1227 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1335 |
| Females | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1238 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 884 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 683 |
| Non-Hispanic blacks | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 568 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 667 |
| Non-Hispanic whites | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 822 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1132 |

< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample. See Appendix A for LODs.

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

topical exposure may occur in occupational exposure settings (e.g., platinum refining plants).

Workplace air standards for external exposure are generally established for soluble salts of platinum by OSHA and ACGIH, or recommended for the metal form by NIOSH (Czerczak & Gromiec, 2000). The pharmaceutical cisplatin is an animal carcinogen as determined by NTP and a possible human carcinogen. The carcinogenicity of other platinum compounds remains uncertain. Information about external exposure (i.e., environmental levels) and health effects is available on line (W.H.O. International Programme on Chemical Safety at http://www.inchem.org).

### Interpreting Levels of Urinary Platinum Reported in the Tables

Urinary platinum levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range

to be a representative sample of the U.S. population. In the NHANES 2001-2002 subsample, as in the previously tested 1999-2000 subsample, urinary platinum levels were detectable in only a few percent of the sample (detection limit was 0.04 µg/L). Older studies reporting measurements in general populations have found detectable and higher values than the value of the detection limit reported in this *Report* (Vaughan et al., 1992; Paschal et al., 1998), which may be due to methodologic, population, or exposure differences. Recently, several studies have shown that background concentrations in general populations are usually less than 0.005 µg/L (Iavicoli et al., 2004; Wilhelm et al., 2003) or less than 0.01 µg/L (Becker et al., 2003; Herr et al., 2003).

One study found that traffic-control police had no greater urinary platinum concentrations than office-based control subjects (Iavicoli et al., 2004). Gold-platinum alloys used for dental fillings also may contribute to urinary platinum concentrations (Schierl, 2001; Herr et al., 2003).

### Table 25. Platinum (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 2465 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 340 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 368 |
| 12-19 years | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 719 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 762 |
| 20 years and older | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1406 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1559 |
| **Gender** | | | | | | | |
| Males | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1227 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1334 |
| Females | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 1238 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 884 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 682 |
| Non-Hispanic blacks | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 568 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 667 |
| Non-Hispanic whites | 99-00 | * | < LOD | < LOD | < LOD | < LOD | 822 |
| | 01-02 | * | < LOD | < LOD | < LOD | < LOD | 1132 |

< LOD means less than the limit of detection, which may vary for some chemicals by year and by individual sample. See Appendix A for LODs.

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

Platinum-industry and precious-metal workers can have urinary concentrations 1,000 times higher than general populations (Schierl et al., 1998). The handling of cisplatin and carboplatin by pharmacy and other hospital personnel has been associated with modest (ten-fold or less) elevations in urinary platinum concentrations (Ensslin et al., 1997; Pethran et al., 2003).

Finding a measurable amount of platinum in urine does not mean that the level of platinum causes an adverse health effect. Whether platinum at the levels reported here is a cause for health concern is not yet known; more research is needed. These urine platinum data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of platinum than are found in the general population. These data will also help scientists plan and conduct research about exposure to platinum and health effects.

# 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 the smelting of 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 pesticidal (rodenticidal, insecticidal, and fungicidal) or cosmetic (depilatory) uses.

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 is slow, occurring via urine and feces.

Thallium produces toxicity by replacing intracellular potassium in the body, though additional mechanisms of action are possible. Since thallium salts are colorless, odorless, and tasteless, there is potential for undetected malevolent use. Severe accidental thallium poisoning has involved the ingestion of rat poisons that contain water-soluble thallium salts. 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.

## Table 26. Thallium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.176** (.162-.192) | **.200** (.180-.210) | **.280** (.260-.310) | **.400** (.370-.420) | **.450** (.420-.470) | 2413 |
| | 01-02 | **.165** (.154-.177) | **.180** (.170-.200) | **.270** (.260-.290) | **.360** (.350-.380) | **.440** (.410-.470) | 2653 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.201** (.167-.243) | **.200** (.150-.260) | **.300** (.250-.350) | **.410** (.330-.450) | **.440** (.350-.590) | 336 |
| | 01-02 | **.172** (.147-.202) | **.200** (.160-.220) | **.290** (.230-.330) | **.340** (.330-.360) | **.380** (.360-.420) | 362 |
| 12-19 years | 99-00 | **.202** (.181-.225) | **.210** (.200-.240) | **.290** (.270-.340) | **.410** (.390-.430) | **.460** (.430-.510) | 697 |
| | 01-02 | **.200** (.182-.220) | **.210** (.190-.240) | **.300** (.290-.320) | **.360** (.340-.390) | **.460** (.400-.500) | 746 |
| 20 years and older | 99-00 | **.170** (.157-.183) | **.180** (.170-.200) | **.290** (.260-.310) | **.400** (.370-.420) | **.450** (.420-.470) | 1380 |
| | 01-02 | **.159** (.147-.173) | **.190** (.170-.200) | **.270** (.250-.290) | **.380** (.350-.400) | **.440** (.400-.490) | 1545 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.197** (.179-.217) | **.220** (.190-.240) | **.310** (.280-.350) | **.390** (.360-.440) | **.440** (.420-.480) | 1200 |
| | 01-02 | **.184** (.173-.196) | **.200** (.190-.220) | **.290** (.270-.290) | **.380** (.350-.390) | **.420** (.390-.460) | 1313 |
| Females | 99-00 | **.159** (.145-.175) | **.180** (.150-.200) | **.270** (.240-.290) | **.380** (.340-.410) | **.450** (.410-.490) | 1213 |
| | 01-02 | **.149** (.137-.163) | **.150** (.150-.170) | **.250** (.230-.280) | **.370** (.330-.400) | **.430** (.400-.500) | 1340 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.172** (.150-.196) | **.190** (.160-.220) | **.260** (.240-.290) | **.370** (.320-.420) | **.450** (.370-.520) | 861 |
| | 01-02 | **.160** (.148-.173) | **.180** (.150-.190) | **.250** (.240-.270) | **.330** (.310-.360) | **.400** (.350-.440) | 675 |
| Non-Hispanic blacks | 99-00 | **.217** (.197-.239) | **.220** (.200-.240) | **.340** (.300-.380) | **.440** (.390-.510) | **.550** (.460-.620) | 561 |
| | 01-02 | **.202** (.187-.218) | **.210** (.200-.230) | **.290** (.270-.330) | **.400** (.380-.440) | **.520** (.440-.590) | 657 |
| Non-Hispanic whites | 99-00 | **.170** (.153-.188) | **.200** (.160-.220) | **.280** (.250-.320) | **.400** (.360-.420) | **.440** (.420-.480) | 801 |
| | 01-02 | **.159** (.147-.172) | **.180** (.160-.190) | **.270** (.250-.290) | **.350** (.320-.380) | **.430** (.390-.460) | 1114 |

Workplace air standards for external exposure are generally established by OSHA and ACGIH. Chronic high-level exposures have been associated with weight loss, arthralgias, and polyneuropathy. 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's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

**Interpreting Levels of Urinary Thallium Reported in the Tables**

Urinary thallium levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range to be a representative sample of the U.S. population. Previous studies have suggested that normal background urinary thallium concentrations are less than 1 µg/L (Schaller et al., 1980; Brockhaus et al., 1981; Minoia et al., 1990), which are consistent with levels documented

in this NHANES 2001-2002 subsample and the previous 1999-2000 subsample. Other population surveys have demonstrated urinary levels of roughly similar magnitude (White and Sabbioni, 1998; Minoia et al., 1990; Paschal et al., 1998).

Urinary concentrations of 100 µg/L in asymptomatic workers (500 times higher than median levels observed in this *Report*) 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 on which thallium had been deposited. Seventy-eight percent of the urine specimens in that study contained more 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 above 20 µg/L.

### Table 27. Thallium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, 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 |
|---|---|---|---|---|---|---|---|
| **Total, age 6 and older** | 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) | **.348** (.337-.365) | 2652 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.221** (.197-.248) | **.221** (.196-.236) | **.292** (.229-.356) | **.375** (.318-.469) | **.424** (.356-.600) | 336 |
| | 01-02 | **.211** (.198-.226) | **.207** (.198-.221) | **.286** (.257-.321) | **.370** (.333-.402) | **.411** (.389-.456) | 362 |
| 12-19 years | 99-00 | **.153** (.146-.160) | **.154** (.146-.162) | **.205** (.191-.219) | **.257** (.231-.278) | **.321** (.265-.364) | 697 |
| | 01-02 | **.143** (.137-.150) | **.145** (.135-.152) | **.196** (.184-.207) | **.269** (.250-.289) | **.307** (.299-.333) | 746 |
| 20 years and older | 99-00 | **.162** (.153-.171) | **.167** (.154-.176) | **.217** (.207-.230) | **.285** (.271-.300) | **.364** (.325-.389) | 1380 |
| | 01-02 | **.153** (.147-.159) | **.152** (.144-.161) | **.210** (.200-.217) | **.277** (.263-.292) | **.342** (.313-.362) | 1544 |
| **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** (.141-.156) | **.192** (.184-.204) | **.259** (.245-.278) | **.307** (.291-.342) | 1312 |
| Females | 99-00 | **.178** (.167-.189) | **.182** (.169-.196) | **.244** (.226-.259) | **.313** (.281-.366) | **.380** (.333-.462) | 1213 |
| | 01-02 | **.167** (.158-.176) | **.167** (.153-.179) | **.233** (.217-.250) | **.313** (.282-.348) | **.375** (.348-.402) | 1340 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.158** (.147-.170) | **.159** (.148-.175) | **.212** (.200-.234) | **.282** (.266-.304) | **.338** (.306-.389) | 861 |
| | 01-02 | **.156** (.145-.169) | **.155** (.145-.167) | **.204** (.190-.221) | **.286** (.250-.315) | **.361** (.301-.424) | 674 |
| Non-Hispanic blacks | 99-00 | **.142** (.133-.152) | **.140** (.129-.151) | **.200** (.184-.214) | **.277** (.244-.307) | **.383** (.286-.462) | 561 |
| | 01-02 | **.138** (.128-.150) | **.136** (.125-.146) | **.194** (.170-.212) | **.256** (.238-.278) | **.321** (.271-.387) | 657 |
| Non-Hispanic whites | 99-00 | **.169** (.160-.179) | **.173** (.167-.181) | **.226** (.215-.240) | **.300** (.271-.325) | **.364** (.333-.377) | 801 |
| | 01-02 | **.161** (.155-.167) | **.161** (.153-.171) | **.220** (.214-.231) | **.291** (.278-.304) | **.347** (.327-.375) | 1114 |

**Comparing Adjusted Geometric Means**

Geometric mean levels of urinary thallium for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). In NHANES 2001-2002, adjusted geometric mean levels of urinary thallium were slightly higher for people aged 6-11 years than for the other two age groups. It is unknown whether these differences associated with age represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding low amounts of thallium in urine does not mean that the level of thallium causes adverse health effects. Whether thallium at the levels reported here is a cause for health concern is not yet known; more research is needed. These urinary thallium data provide physicians with a reference range so that they can determine whether individuals or groups have been exposed to higher levels of thallium than are found in the general population. These data will also help scientists plan and conduct research about thallium exposure and health effects.

## Figure 11. Thallium (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
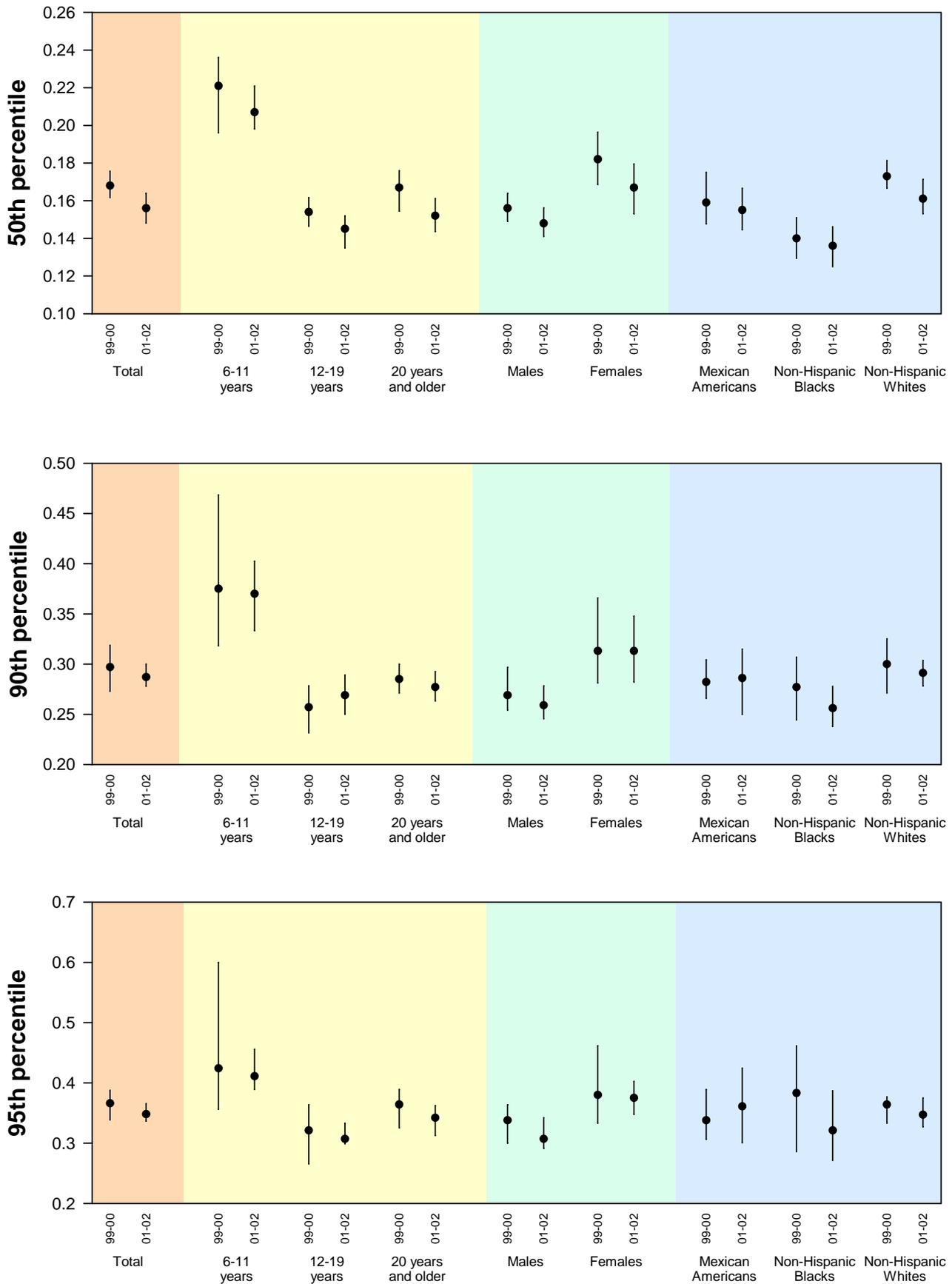
# Tungsten

CAS No. 7440-33-7

## General Information

Tungsten is a steel-gray to tin-white metal naturally occurring in the earth's crust, mainly as scheelite ($CaWO_4$). A major use of tungsten is in the production of hard metals, such as tungsten carbide, which is used in rock drills and metal-cutting tools, and ferrotungsten, which is used in the steel industry. Additionally, 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, whereas occupational exposure is from tungsten metal dusts released during the grinding or drilling of metals. Drinking water also can be a source of exposure. Workplace air standards for external exposure have been established by ACGIH or recommended by NIOSH. Evidence is lacking for the carcinogenicity of tungsten; it has not been classified with respect to its carcinogenicity by either IARC or NTP.

Only limited information is available on the toxicity of tungsten. Human illness from low-level environmental or occupational exposure has not been well established. Although workers occupationally exposed to tungsten carbide may develop serious lung disease ("hard metal" disease), their illness may stem from co-exposure to cobalt mixed with tungsten carbide rather than to tungsten itself.

## Table 28. Tungsten

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.093** (.087-.100) | **.090** (.080-.090) | **.180** (.160-.190) | **.320** (.280-.360) | **.500** (.420-.550) | 2338 |
| | 01-02 | **.082** (.073-.092) | **.060** (.060-.080) | **.150** (.130-.180) | **.300** (.260-.340) | **.450** (.370-.560) | 2652 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.158** (.123-.204) | **.160** (.100-.200) | **.260** (.210-.330) | **.490** (.380-.560) | **.590** (.510-.950) | 320 |
| | 01-02 | **.137** (.110-.170) | **.140** (.100-.160) | **.250** (.200-.340) | **.450** (.360-.690) | **.770** (.510-1.53) | 363 |
| 12-19 years | 99-00 | **.113** (.097-.132) | **.110** (.090-.120) | **.200** (.170-.230) | **.360** (.300-.430) | **.530** (.380-.800) | 679 |
| | 01-02 | **.113** (.095-.135) | **.100** (.090-.130) | **.210** (.180-.240) | **.390** (.310-.520) | **.570** (.430-.710) | 744 |
| 20 years and older | 99-00 | **.084** (.078-.091) | **.070** (.060-.080) | **.150** (.130-.180) | **.270** (.250-.320) | **.440** (.360-.520) | 1339 |
| | 01-02 | **.073** (.065-.082) | **.060** (.050-.060) | **.130** (.110-.160) | **.250** (.210-.300) | **.370** (.300-.490) | 1545 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.107** (.096-.120) | **.100** (.080-.110) | **.210** (.180-.230) | **.380** (.310-.470) | **.530** (.470-.650) | 1160 |
| | 01-02 | **.088** (.074-.105) | **.080** (.060-.090) | **.160** (.130-.210) | **.330** (.260-.390) | **.490** (.380-.580) | 1307 |
| Females | 99-00 | **.082** (.077-.087) | **.070** (.060-.070) | **.140** (.130-.160) | **.270** (.240-.290) | **.390** (.320-.470) | 1178 |
| | 01-02 | **.076** (.069-.084) | **.060** (.050-.060) | **.140** (.120-.170) | **.280** (.230-.320) | **.430** (.330-.530) | 1345 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.113** (.095-.133) | **.100** (.090-.120) | **.190** (.160-.240) | **.390** (.300-.520) | **.550** (.420-.830) | 790 |
| | 01-02 | **.101** (.093-.109) | **.090** (.080-.110) | **.180** (.170-.200) | **.370** (.310-.430) | **.560** (.450-.670) | 680 |
| Non-Hispanic blacks | 99-00 | **.113** (.101-.126) | **.090** (.080-.110) | **.200** (.170-.240) | **.360** (.290-.460) | **.550** (.420-.810) | 562 |
| | 01-02 | **.096** (.080-.116) | **.080** (.060-.110) | **.150** (.120-.230) | **.310** (.270-.400) | **.460** (.390-.580) | 649 |
| Non-Hispanic whites | 99-00 | **.092** (.084-.100) | **.070** (.060-.090) | **.170** (.150-.190) | **.310** (.270-.380) | **.460** (.380-.520) | 802 |
| | 01-02 | **.076** (.066-.088) | **.050** (.040-.070) | **.150** (.120-.170) | **.290** (.230-.350) | **.430** (.330-.560) | 1117 |

**Interpreting Levels of Urinary Tungsten Reported in the Tables**

Urinary tungsten levels were measured in a subsample of NHANES participants aged 6 years and older. Participants were selected within the specified age range to be a representative sample of the U.S. population. A nonrandom subsample from NHANES III demonstrated higher values than those in this *Report* (Paschal et al., 1998), possibly due to methodologic, population, or exposure differences. One small study of unexposed individuals (n = 14) yielded values similar to those reported here (Schramel et al., 1997). Median urinary tungsten levels may be increased as much as 15-fold over median levels in this *Report* due to natural increases in drinking water sources (CDC, 2003*b*). During grinding operations that release tungsten metal into the air, workers had elevated urinary tungsten levels that were more than 900 times higher than the overall geometric mean in the NHANES 1999-2000 subsample (Kraus et al., 2001). The application of the technique of neutron

activation analysis to a control group of non-metal workers showed mean urinary tungsten levels similar to levels at the 95th percentile of the NHANES 1999-2000 subsample, whereas the tungsten-worker group had mean urine levels 35 times higher (Nicolaou et al., 1987). Patients with medically-inserted tungsten embolization coils showed elevated tungsten levels in blood, urine, and hair (Bachthaler et al., 2004). Urinary tungsten levels in these patients were often hundreds-fold higher than demonstrated in this *Report*.

**Comparing Adjusted Geometric Means**

Geometric mean levels of urinary tungsten for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). In NHANES 2002-2002, the group aged 6-11 years had higher adjusted geometric mean levels of urinary tungsten than either of the groups aged 12-19 years or 20 years and older. The group aged 12-19 years had higher

### Table 29. Tungsten (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.087** (.080-.095) | **.080** (.075-.086) | **.146** (.136-.158) | **.270** (.206-.333) | **.381** (.302-.459) | 2338 |
| | 01-02 | **.078** (.069-.087) | **.074** (.064-.084) | **.138** (.122-.154) | **.255** (.216-.300) | **.359** (.315-.436) | 2651 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.174** (.150-.201) | **.169** (.136-.198) | **.293** (.216-.333) | **.438** (.331-.667) | **.614** (.452-.880) | 320 |
| | 01-02 | **.168** (.144-.197) | **.158** (.139-.188) | **.275** (.231-.326) | **.412** (.333-.554) | **.634** (.436-1.28) | 363 |
| 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) | **.147** (.122-.167) | **.250** (.208-.301) | **.359** (.272-.431) | 744 |
| 20 years and older | 99-00 | **.080** (.072-.089) | **.074** (.067-.082) | **.130** (.115-.143) | **.218** (.179-.301) | **.339** (.245-.426) | 1339 |
| | 01-02 | **.070** (.063-.079) | **.067** (.057-.075) | **.119** (.099-.139) | **.214** (.176-.267) | **.321** (.250-.429) | 1544 |
| **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) | **.064** (.056-.077) | **.125** (.098-.152) | **.255** (.203-.306) | **.364** (.300-.431) | 1306 |
| 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** (.128-.162) | **.258** (.216-.317) | **.353** (.317-.538) | 1345 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.106** (.093-.120) | **.100** (.086-.115) | **.184** (.152-.214) | **.327** (.267-.392) | **.493** (.354-.727) | 790 |
| | 01-02 | **.098** (.090-.108) | **.089** (.081-.100) | **.163** (.143-.187) | **.294** (.256-.370) | **.554** (.410-.797) | 679 |
| 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 |
| Non-Hispanic whites | 99-00 | **.091** (.083-.100) | **.081** (.077-.088) | **.149** (.135-.167) | **.278** (.200-.354) | **.383** (.302-.462) | 802 |
| | 01-02 | **.078** (.068-.088) | **.073** (.061-.085) | **.138** (.120-.156) | **.253** (.209-.308) | **.353** (.286-.453) | 1117 |

levels than the group aged 20 years and older. Levels in Mexican Americans were higher than in non-Hispanic blacks and non-Hispanic whites. It is unknown whether these differences associated with age or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of tungsten in urine does not mean that the level of tungsten causes an adverse health effect. Whether tungsten at the levels reported here is a cause for health concern is not yet known; more research is needed. These urinary tungsten data provide physicians with a reference range so that they can determine whether or not people have been exposed to higher levels of tungsten than are found in the general population. These data will also help scientists plan and conduct research about exposure to tungsten and health effects.

## Figure 12. Tungsten (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.
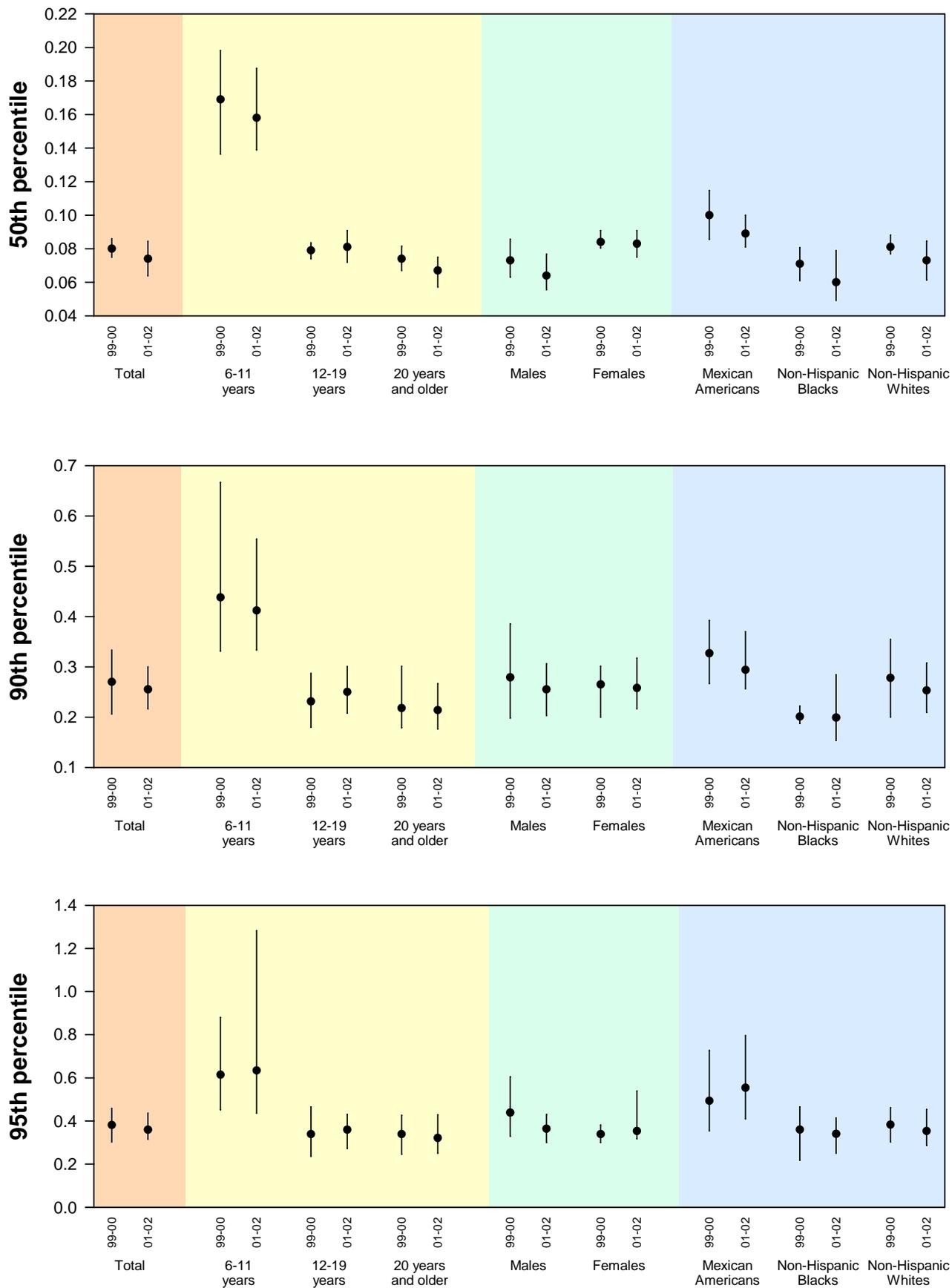
# Uranium

CAS No. 7440-61-1

## General Information

Uranium is a silver-white, extremely dense, and weakly radioactive metal. It is typically extracted from ores containing less than 1% natural uranium. Natural uranium is a mixture of three isotopes: $^{238}$U (99.2739%), $^{235}$U (0.7204%), and $^{234}$U (0.0057%). It usually occurs as an inorganic compound with oxygen, chlorine, or other elements. Uranium has many commercial uses, including its use in 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 proportion of $^{235}$U and $^{234}$U isotopes have been reduced, compared with the proportion in natural uranium. DU is used in the production of armor-piercing projectiles.

Human exposure to uranium occurs primarily in the workplace by inhaling dust and other small particles. Exposure to insoluble uranium oxides and uranium metal via inhalation results in retention of these forms of uranium in the lungs and other tissues with little excretion in the urine. Soluble forms of uranium salts are poorly absorbed in the gastrointestinal tract, but these small amounts can be reflected in urinary measurements. Some uranium can be absorbed from food and water, especially in areas where large amounts of uranium occur naturally. Soluble uranium compounds may exhibit some dermal absorption. Exposure to DU can occur after internal contact with DU-containing shrapnel or dust.

After absorption, soluble uranium is predominantly distributed to the kidneys and the bones. Approximately 50% of uranium is eliminated in the urine within the first

## Table 30. Uranium

Geometric mean and selected percentiles of urine concentrations (in µg/L) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

| | Survey years | Geometric mean (95% conf. interval) | Selected percentiles (95% confidence interval) | | | | Sample size |
|---|---|---|---|---|---|---|---|
| | | | 50th | 75th | 90th | 95th | |
| **Total, age 6 and older** | 99-00 | **.008** (.007-.009) | **.007** (.006-.007) | **.013** (.010-.016) | **.026** (.021-.038) | **.046** (.036-.054) | 2464 |
| | 01-02 | **.009** (.007-.010) | **.008** (.006-.009) | **.014** (.011-.016) | **.029** (.022-.037) | **.046** (.034-.062) | 2690 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.009** (.007-.011) | **.007** (.005-.007) | **.013** (.009-.019) | **.032** (.018-.048) | **.046** (.033-.066) | 340 |
| | 01-02 | **.008** (.007-.010) | **.008** (.006-.010) | **.014** (.010-.020) | **.025** (.020-.036) | **.037** (.025-.049) | 368 |
| 12-19 years | 99-00 | **.009** (.008-.011) | **.009** (.008-.010) | **.014** (.012-.018) | **.025** (.020-.043) | **.043** (.028-.072) | 719 |
| | 01-02 | **.010** (.008-.012) | **.009** (.008-.012) | **.017** (.012-.023) | **.030** (.021-.042) | **.041** (.027-.088) | 762 |
| 20 years and older | 99-00 | **.008** (.006-.009) | **.007** (.005-.008) | **.012** (.009-.016) | **.026** (.021-.038) | **.045** (.035-.054) | 1405 |
| | 01-02 | **.009** (.007-.010) | **.007** (.006-.009) | **.014** (.011-.016) | **.030** (.022-.039) | **.046** (.034-.059) | 1560 |
| **Gender** | | | | | | | |
| Males | 99-00 | **.009** (.008-.011) | **.007** (.007-.010) | **.015** (.012-.020) | **.036** (.024-.046) | **.053** (.040-.067) | 1227 |
| | 01-02 | **.009** (.008-.011) | **.008** (.007-.010) | **.014** (.012-.019) | **.033** (.023-.043) | **.046** (.035-.065) | 1335 |
| Females | 99-00 | **.007** (.006-.008) | **.006** (.005-.007) | **.011** (.009-.014) | **.023** (.016-.032) | **.035** (.026-.050) | 1237 |
| | 01-02 | **.008** (.007-.010) | **.008** (.006-.009) | **.013** (.011-.016) | **.027** (.018-.037) | **.040** (.029-.062) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.017** (.012-.023) | **.015** (.011-.021) | **.032** (.019-.053) | **.059** (.040-.127) | **.113** (.054-.279) | 883 |
| | 01-02 | **.013** (.010-.016) | **.011** (.009-.015) | **.022** (.016-.027) | **.039** (.031-.054) | **.054** (.045-.067) | 683 |
| Non-Hispanic blacks | 99-00 | **.009** (.007-.011) | **.007** (.006-.010) | **.013** (.010-.019) | **.028** (.018-.045) | **.049** (.030-.067) | 568 |
| | 01-02 | **.008** (.007-.009) | **.007** (.007-.009) | **.012** (.010-.013) | **.020** (.017-.027) | **.030** (.023-.037) | 667 |
| Non-Hispanic whites | 99-00 | **.007** (.006-.009) | **.007** (.005-.007) | **.012** (.008-.014) | **.023** (.016-.033) | **.041** (.027-.051) | 822 |
| | 01-02 | **.008** (.007-.009) | **.006** (.006-.008) | **.012** (.010-.014) | **.026** (.018-.034) | **.036** (.028-.049) | 1132 |

24 hours after exposure. Following exposure to soluble uranium salts, the initial half-life of uranium is considered to be about 15 days (Bhattacharyya et al., 1992), representing distribution and excretion, with a much slower elimination from bone. After inhalation exposure of insoluble uranium, the half-life for disappearance from the lung is several years (Durakovic et al., 2003).

Health effects from uranium exposure occur from chemical toxicity. Radiation risks from exposure to natural uranium are very low. Nephrotoxicity, the primary toxic effect attributed to chronic uranium exposure in people, manifests as tubular damage and appears reversible with decreasing exposure. Workplace air standards for external exposure to soluble and insoluble uranium compounds have been established by OSHA and ACGIH. Although older evaluations suggested the carcinogenicity of uranium among smokers, the U.S. EPA has withdrawn its classification for carcinogenicity; IARC and NTP have no ratings.

Information about external exposure (i.e., environmental levels) and health effects is available from the U.S. EPA's IRIS Web site at http://www.epa.gov/iris and from ATSDR's Toxicological Profiles at http://www.atsdr.cdc.gov/toxprofiles.

### Interpreting Levels of Urinary Uranium Reported in the Tables

Urine uranium levels were measured in a subsample of NHANES participants aged 6 years old and older. Participants were selected within the specified age range to be a representative sample of the U.S. population. The analytical method measures only levels of the $^{238}U$ isotope and not levels of the $^{235}U$ isotope ($^{235}U$ is higher in enriched uranium used as nuclear fuel). More than 99% of naturally occurring uranium is $^{238}U$.

A previous nonrandom subsample from NHANES III (n = 499) showed concentrations that are essentially similar to those in this *Report* (Ting et al., 1999). Dang et

## Table 31. Uranium (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, 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 |
|---|---|---|---|---|---|---|---|
| **Total, age 6 and older** | 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-.033) | **.040** (.028-.054) | 2689 |
| **Age group** | | | | | | | |
| 6-11 years | 99-00 | **.009** (.007-.012) | **.008** (.006-.010) | **.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 |
| 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** (.014-.026) | **.026** (.020-.042) | 762 |
| 20 years and older | 99-00 | **.007** (.006-.009) | **.007** (.005-.008) | **.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 |
| **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 |
| Females | 99-00 | **.008** (.007-.010) | **.007** (.006-.009) | **.013** (.010-.017) | **.024** (.019-.033) | **.034** (.027-.054) | 1237 |
| | 01-02 | **.009** (.008-.011) | **.009** (.007-.011) | **.016** (.012-.021) | **.029** (.021-.042) | **.045** (.031-.067) | 1355 |
| **Race/ethnicity** | | | | | | | |
| Mexican Americans | 99-00 | **.015** (.011-.022) | **.015** (.011-.020) | **.028** (.016-.058) | **.059** (.027-.146) | **.100** (.042-.270) | 883 |
| | 01-02 | **.012** (.010-.016) | **.012** (.009-.016) | **.021** (.015-.028) | **.033** (.024-.053) | **.049** (.033-.077) | 682 |
| Non-Hispanic blacks | 99-00 | **.006** (.004-.007) | **.005** (.004-.006) | **.008** (.006-.013) | **.017** (.011-.028) | **.028** (.018-.048) | 568 |
| | 01-02 | **.005** (.005-.006) | **.005** (.005-.006) | **.008** (.007-.010) | **.013** (.011-.014) | **.017** (.014-.029) | 667 |
| 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 |

al. (1992), Karpas et al. (1996), and Galletti (2003) reported urinary levels for small groups of normal individuals in a range similar to those values seen in both the 1999-2000 and 2001-2002 subsamples. In addition, other studies have demonstrated urinary uranium concentrations that are consistent with levels documented in this *Report*, in that the reported levels were below their respective detection limits (Hamilton et al., 1994; Komaromy-Hiller et al., 2000; Byrne et al., 1991).

In one study, 105 people exposed to well water containing natural uranium in the range of 1.8 to 7770 μg/L (median 157 μg/L) had urinary levels of uranium as high as 9.55 μg/L (median 0.162 μg/L)(Orloff et al., 2003). Eighty-five percent of the levels were above the 95th percentile of the NHANES 1999-2000 subsample. In another study of people drinking well water with high natural uranium concentrations, the median urinary concentration was 0.078 μg/L (ranging up to 5.65 μg/L), and a subtle effect of uranium on calcium and phosphate fractional clearance was indicated (within the normal range of these measures), but without effects on other biochemical or traditional markers of renal function (Kurttio et al., 2002). The urinary uranium levels reported here for the NHANES 2001-2002 subsample are well below any of these aforementioned levels.

The U.S. Nuclear Regulatory Commission (U.S. NRC) has set an action level of 15 μg/L for uranium in urine to protect people who are occupationally exposed to uranium (U.S. NRC, 1978). Six workers in a depleted uranium program had concentrations of 0.110 to 45 μg/L (Ejnik et al., 2000). Several recent studies have investigated urinary uranium levels in veterans who served during the 1991 Gulf War. In one study, 17 soldiers with embedded shrapnel had a median urinary uranium concentration of 2.61 μg/g creatinine and 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 a group 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).

**Comparing Adjusted Geometric Means**

Geometric mean levels of urinary uranium for the demographic groups were compared after adjusting for the covariates of race/ethnicity, age, gender, log serum cotinine, and urinary creatinine (data not shown). In NHANES 2001-2002, adjusted geometric mean levels of urinary uranium in the group aged 6-11 years were

higher than the groups aged 12-19 years. Mexican Americans had higher levels than either non-Hispanic blacks or non-Hispanic whites, and non-Hispanic whites had higher levels than non-Hispanic blacks. Females had slightly higher adjusted geometric mean levels of urinary uranium than males. It is unknown whether these differences associated with age, gender, or race/ethnicity represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight.

Finding a measurable amount of uranium in urine does not mean that the level of uranium causes an adverse health effect. Whether uranium at the levels reported here is cause for health concern is unknown; more research is needed. These urinary uranium data provide physicians with a reference range so that they can determine whether people have been exposed to higher levels of uranium than are found in the general population. These data will also help scientists plan and conduct research about uranium exposure and health effects.

# Figure 13. Uranium (creatinine corrected)

Selected percentiles with 95% confidence intervals of urine concentrations (in µg/g of creatinine) for the U.S. population aged 6 years and older, National Health and Nutrition Examination Survey, 1999-2002.

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