Chapter-15

EXPOSURE TO MERCURY IN THE AMERICAS

Kathryn R. Mahaffey

Office of Science Coordination and Policy, United States Environmental Protection Agency
Washington, D.C. 20640, USA

INTRODUCTION

Non-occupational exposures of the human population to mercury occur predominantly as methylmercury from fish and shellfish consumption and as inorganic mercury among the segment of the population for whom silver-mercury amalgams have been used in dental restorations. These sources of exposure are sufficiently common as to constitute the background onto which additional sporadic exposures are added. Examples of the latter include mercury in cosmetics, folk remedies, cultural practices, accidents, and forensic or use of mercury as a poison.

Occupational exposures which cover a wide range of types of work (e.g., chloralkali factory workers, dentists, dental technicians, gold miners) are predominantly to inorganic mercury, mercury vapors, and various mercury salts. The rare occupational exposure to organo-mercurials has proven extremely dangerous. However, organo-mercurial residues have been identified in environmental samples at former mercury plants where organo-mercurials for pesticide use were produced (Hempel et al., 1995).

This chapter provides an overview of reports on sources of mercury in the Americas during the past 30 years. The descriptions are for specified subgroups and usually provide no indication of the prevalence of the exposures in the general population. The usual situation relies on reported mercury exposures in a geographic location, a cohort, an occupation, a poisoning episode, or in some other subgroup.

Based on this collage of data describing the magnitude of mercury exposures in the Americas, an estimate of the sources and pervasiveness of the mercury exposures emerges. This chapter does not compare exposure estimates with risk values for methylmercury (e.g., NAS/NRC, 2000; Rice et al., 2003; JECFA, 2003).

BIOLOGICAL INDICATORS OF MERCURY EXPOSURE

Biomarkers of Mercury Exposure

Environmental data describing mercury concentrations in media including air, water, sediments, biota, etc. indicate the magnitude of contamination of various routes of mercury exposure. In risk assessments relating mercury exposure to health effects, dose-response for a group of individuals may include consideration of biomarkers of exposure to the prevalence of adverse health effects. Chemical analyses of body fluids and tissues provide an indication of the chemical species of mercury to which the person was exposed, the magnitude, the time and duration of the exposure. Whole blood, urine, and hair are the body fluids and products typically analyzed to determine their mercury concentration to provide an indication of the person's mercury exposures. These three tissues provide diverse information. For example, blood mercury typically is used to indicate exposure to organic mercury, almost always dominated by methylmercury. Urinary mercury is an indicator of exposure to inorganic mercury. Hair mercury is dominated by exposure to methylmercury. Because mercury can deposit on hair from surface contamination, total mercury content of hair may not be a reflection of mercury excreted from the body, but may be dominated by mercury from surface contamination. In depth review articles on this topic include: Risher et al. (2002), Mason et al. (2001). Veiga (2004) provides guidance on practical aspects of collection of environmental and human biological samples for evaluation of exposure to mercury vapor, inorganic mercury and methylmercury. Veiga (2004) also reviews in-depth methodologies for analyses that provide both total and chemically speciated mercury concentrations. A brief overview of the relationship of chemical species of mercury to mercury concentrations in biological materials used as biomarkers of exposure follows.

Chemical Forms of Mercury to Which People Are Commonly Exposed

Methylmercury. More than 95% of methylmercury present in diet is absorbed from the gastrointestinal tract. The half-life of total blood mercury in human adults is generally given as approximately 70 days, however, individual values as long as 250 days have been reported by Birke et al. (1972). Based on data from 48 patients al-Shahristani and Shihab (1974) reported that biological half-times of blood mercury varied between 37 and 189 days, with an average of 72 days. The half-life of methylmercury in blood has been estimated to be 44 days based on single exposure intravenous injection of radio-labeled methylmercury (Smith et al., 1994). Based on results from Kershaw et al. (1980) elimination of methylmercury from blood had a biphasic half-time of 7.6 hours (range 4.9 hours to 9.5 hours) and 52 days (range 39 days to 66 days) following consumption of single serving of high-mercury fish (Kershaw et al., 1980). Sherlock et al. 1984 reported a half-time of 50 days (range 42 to 70 days) for methylmercury from consumption of fish over a period of several weeks in a group of adult volunteers.

Among the general population in the United States when total blood mercury exceeded ~ 4 μg/L more than 90% of the mercury present was organic mercury (Mahaffey et al., 2004). The source of organic mercury for the general population is methylmercury from the consumption of fish and shellfish.

Inorganic mercury. Blood inorganic mercury concentrations have been used to detect acute, high dose exposures. At high exposures the cell-to-plasma ratio ranges from a high of two to less than one (Goyer and Clarkson, 2001; Mason et al., 2001). Alternately monitoring of urine is the indicator for exposure to chronic, low-to-moderate inorganic mercury exposure (Mason et al., 2001). Health risks associated with various values are discussed elsewhere. The distribution of inorganic mercury concentrations is discussed below.

The half-life of inorganic mercury in blood is about three days based on experimental studies with radio-labeled mercury (Cherian et al., 1978). A second slower half-life of about two to three weeks has been indicated based on studies in chloralkali workers whose exposures were terminated (Barregard et al., 1992). Urinary levels are used to monitor sustained exposure to inorganic mercury.

Mercury vapor. An excellent recent review of the health effects of mercury vapor is provided in the UNIDO Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners (Veiga, 2004). Inhalation of mercury vapor is the most significant form of mercury exposure for mining and gold shop workers engaged in these types of

mining operations. Once inside the lungs mercury is oxidized forming Hg (II) complexes which are soluble in many body fluids.

The half-time of Hg in blood absorbed as a vapor is 2 to 4 days after which 90% is excreted through urine and feces followed by a second phase with a half-time of 15-30 days (WHO, 1991). Between passage of elemental mercury through the alveolar membrane and complete oxidation, mercury accumulates in the central nervous system (Mitra, 1986). During this process mercury can irreversibly damage the central nervous system. At exposures of moderate duration, the kidneys are also affected. Short-term exposure to high levels of mercury vapor produces chest pain, dyspnea, cough impaired pulmonary function, interstitial pneumonitis (Veiga, 2004; WHO, 1991). Occupational exposures to mercury vapor have caused psychiatric symptom, hallucinations, erethism (exaggerated emotional response), insomnia, and muscular tremors (WHO, 1991).

Ethylmercury, Phenylmercury and Other Mercury Compounds Ethylmercury has been added as a preservative to vaccines and biologicals since the 1930s (Midthun, 2004). The metabolism of ethylmercury administered by intramuscular injection (as it would be used in vaccines) differs from methylmercury based on studies with primates (Burbacher et al, 2004). Compared with methlymercury, ethylmercury derived from thimerosal has a shorter terminal half-life in both blood and brain. In young monkeys, Burbacher et al. (2004) found minimal accumulation of total blood mercury from ethylmercury derived from thimerosal, but found that the brain-to-blood partition ratio for ethyl mercury was higher than that for methylmercury. Earlier work by Pichichero et al. (2002) had reported that the blood half-life for ethylmercury in human infants was 7 days, substantially shorter than the half-life of methylmercury. Measurement of blood mercury levels in infants 48 to 72 hours after hepatitis B vaccinations at birth showed a substantial elevation in their blood mercury concentration (Stajich et al., 2000).

Phenylmercury is absorbed from the gastrointestinal tract and excreted in the urine based on studies with adult volunteers. This form of mercury has been used as a preservative in cosmetics and has been used as an anti-infection agent in products such as mouth washes (Lauwerys et al., 1977). A study with adult human volunteers (Lauwerys et al., 1977) showed use of these products resulted in a marked increased urinary mercury excretion and an increase in blood mercury concentration with even very short-term use. Use of hand soap containing phenylmercuric borate was associated with increased urinary mercury among adult male and female health professionals using the soap as a disinfectant in hand cleaning (Peters-Haefeli et al., 1976). It was estimated that use of hand soap containing 0.04% phenylmercuric borate increased daily

mercury absorption between 30 to 100 μg Hg/24 hours, in part due to hand-to-mouth transfer of mercury.

Biological Media Used to Indicate Mercury Exposure

Blood Mercury. Blood mercury concentration is the preferred biomarker for exposure to methylmercury. When blood mercury exceeded ~ 4 μg/L, more than 90% of mercury in blood was present as organic or methylmercury in adult women in a sample representative of the United States population (Mahaffey et al., 2004). At lower blood mercury concentrations in the range of 1 μg/L to 2 μg/L blood mercury indicates exposures to both inorganic mercury and methylmercury (Mahaffey et al., 2004; Morrissette et al., 2004). Whether the inorganic form or methyl form predominates, depends on the relative contribution to the total mercury burden of fish consumption vs. dental amalgams.

In occupational settings where there is high exposure to mercury vapor, blood inorganic mercury has been found to be elevated and closely correlated with urinary mercury (e.g., data on chlor-alkali workers - see Smith et al., 1970). These findings were reported from subjects whose exposures ranged to levels far higher than observed in the general population in the Americas; i.e., > 20-30 μg/L whole blood. Exposure to mercury vapor may occur non-occupationally in mercury spills or in ritualistic use of mercury (see 4.7 below).

Urinary mercury. Urine mercury concentration is usually expressed in μg/L. Frequently mercury concentrations are adjusted for creatinine excretion. Creatinine is excreted by the kidneys and is a breakdown produce of creatine which is a constituent of muscle. Creatinine excretion depends on muscle mass so values for a person are relatively constant depending on age and lean body mass. Creatinine concentrations are usually expressed in mg/dL. Urinary values expressed simply in volume (per L) are subject to dilution and consequently more variable with the quantity of fluids consumed.

The half-life of urinary excretion of mercury has been reported to range from as short as 20 days to as long as 90 days (Mason et al., 2001). Based on likely half-lives of 40 to 90 days, urinary mercury is an integrated marker of exposure over previous months (Mason et al., 2001).

Reference published for urinary mercury, e.g., Iyenger and Woittiez (1988) indicated the 95% upper confidence limit was < 20 μg/L. Among the 1748 women aged 16-49 years who participated in the 1999-2000 NHANES, the 95th percentile value was 5 μg/L or 3.27 μg Hg/g creatinine (CDC, 2003).

Urinary mercury is the preferred biomarker for exposure to inorganic mercury

and over time increases in response to exposure to low levels of mercury vapor. Mercury concentrations in the urine will also increase with exposure to other mercurials including phenylmercury. Inorganic mercury can also arise from demethylation of methylmercury. An increase in urinary inorganic mercury can be shown in subjects with a high methylmercury intake (Carta et al., 2003; Johnsson et al., 2004).

Hair mercury. Growth, morphology and histochemistry of human hair have been reviewed in detail (Swift, 1997). Hair is approximately 95% proteinaceous and 5% a mixture of lipids, glycoproteins, remnants of nucleic acids, and in the case of pigmented hairs of melanin and phaeomelanin. Hair contains a central core of closely packed spindle-shaped cortical cells, each filled with macrofibrils which, in turn, consists of microfibril/matrix composit. The amino acid composition of hair is high in those amino acids with side-chains (particularly, those containing cystine, cysteine, tyrosine, and tryptophan). The cortical core is covered by some sheet-like cells of the cuticle. The surfaces of all of the hair shaft have a thin layer of lipids which is covalently attached to the underlying protein.

As hair grows methylmercury is incorporated into hair. There is a general view that hair grows about 1 cm per month, although there is evidently substantial variability around this value. Hair mercury analyses are complicated by the problem of deposition of mercury onto the hair after it has been formed from external sources including cosmetics (e.g., dyes and Hg^0 vapors).

Hair mercury is predominantly methylmercury, but the percent of total hair mercury that is methylmercury has been reported to be 80% (WHO, 1990) to values ranging from 90% to 98% (Dolbec et al., 2000). Generally hair is thought to be 250 to 300 times more concentrated in mercury than is blood (WHO, 1990; Veiga, 2004), although lower values have also been given including a range of 150 to 200 (Gill et al., 2002). A far wider range of individual values exists. For example, Dolbec et al. (2000) reported hair to blood ratios ranging between 81 and 624. The extent to which this ratio is applicable across all age and ethnic/racial groups remain to be confirmed. Seidel et al. (2001) have noted many problems with commercial laboratories performing hair analyses for trace elements.

Inorganic mercury is not considered to be excreted in hair, although inorganic mercury can be a surface contaminant on hair. Hair is not considered as good an indicator of exposure to mercury vapor (Veiga, 2004) or to inorganic mercury (Veiga, 2004) as is urine.

Biological Variation by Age, Gender and Physiological Status

Because concentrations of mercury in human tissues are determined by environmental exposures to mercury, it is difficult to describe biological variation by age, gender, and physiological status, with a few exceptions. The generalities are that exposures depend more on the work habits and food consumption habits of the population being described. If mercury exposures are unusually high in a particular occupation, for example dentistry, the sex distribution of professionals in that occupation will, of course, greatly influence sex-related differences in that particular
occupational exposure. With regard to methylmercury, if methylmercury were closely tied to caloric intakes per kilogram of body weight, men would consistently have higher exposures to methylmercury than women. However, methylmercury exposure is closely linked to consumption of fish and shellfish, in general, and to consumption of high-trophic level piscivorous fish, in particular. Consequently eating patterns of particular species of fish and shellfish predict dietary intakes of methylmercury.

Generally men have higher intakes of methylmercury on a per kilogram body weight basis than do women, as well as having higher hair and blood mercury concentrations. Higher mercury exposures among men have been identified in some data sets (e.g., Dolbec, et al., 2000). However, the gender-associated difference is not consistent. For example, Kosatsky et al. (2000) found no association between gender and mercury exposure among sports fish consumers.

Some major data sets report an increase in blood mercury concentrations with age among women of reproductive age. Examples of data sets in which blood mercury levels increased with age are results from the 1709 women ages 16 through 49 who were examinees in the 1999-2000 National Health and Nutrition Examination Survey in the United States (Mahaffey et al., 2004) and the cord blood mercury data for a group of ~1100 southern Quebec, Canadian women reported by Rhiands et al. (1999). Other data sets indicate no increase in concentration of mercury with age (among others see Kosatsky et al., 2000).

One pattern that has consistently been identified in data from multiple sources is the ratio of cord blood mercury concentration to maternal blood mercury concentration. Cord blood averages 70% to 80% higher than maternal blood based on analyses of matched cord maternal pairs (Sterns and Smith, 2003). In addition to the data sets included in the analyses by Sterns and Smith (2003), several published subsequently from diverse parts of the world have provided subsequent confirmation of this ratio. Among others see: Muckle et al. (2001) among the northern Quebec Inuits; Morrisette et al. (2004), among women living along the St. Lawrence River; Sakamoto et al. (2004) among

Japanese women.

Blood mercury levels among children have to be interpreted with knowledge of the child's age and degree of mercury exposure. At birth newborns have higher blood mercury concentrations than their mothers. These blood mercury concentrations appear to decline rapidly in populations with low mercury exposures.

For example, in the NHANES data (Schober et al., 2003), children's blood concentrations were approximately one-fourth as high as those of adult female examinees. Hair mercury concentrations among 1-through-5 year-old children were less than one-half those of the women ages 16-through-49 years (McDowell et al., 2004). By contrast, under conditions when methylmercury exposures are substantially higher, children's mercury concentrations do not differ very much from those of adults. For example, Santos et al. (2002) found mean hair mercury concentrations of children aged 7 to 12 years were 14.4 μg/g, compared with 15.7 μg/g for adult women aged 14 to 44 years, and 14.1 μg/g for all other people in their sample.

HUMAN DATA INDICATING MERCURY EXPOSURE IN THE AMERICAS

Most reports on mercury exposure have aimed to evaluate populations thought to be at risk of exposure to amounts of mercury thought to be problematic. Efforts to identify data that provide reference ranges for the population not considered at unusual risk of exposure and located in the Americas are few. General population data for the entire age and gender range appear not to be available for any country in the Americas.

United States of America

The recent United States data on blood mercury and hair mercury concentrations are limited to women of childbearing age and children. Data on adult males will be reported only beginning with examinees who participated in the National Health and Examination Surveys (NHANES) in 2003 and later. These data are unlikely to be published until late 2005 or 2006. Estimates of exposures to people considered to have no unusual risk of mercury exposure can be inferred by looking at data from groups selected as "controls" when evaluating "exposed" groups.

Surveys among the General Population

The largest study of men from the general population is that of Kingman et al. (1998) who analyzed urine and blood mercury concentration among 1127 Vietnam-era United states Air Force pilots (all men, average age 53 years at the time of blood collection) for whom extensive dental records were available. Blood values were determined for total mercury, inorganic mercury and organic/methylmercury. The mean total blood mercury concentration was 3.1 μg/L with a range of "zero" (i.e., detection limit of 0.2 μg/L) to 44 μg/L. Overall, 75% of total blood mercury was present as organic or methylmercury. Less than 1% of the variability in total blood mercury was attributable to variation in the number and size of silver-mercury amalgam dental restorations. Dietary data on the former pilots were very limited, so typical patterns of fish consumption were not reported.

Table 1. Total Blood Mercury (μg/L) for Women Ages 16-49 Years among the 1999-2000 NHANES Examinees (Mahaffey et al., 2004).

	Sample Persons	Geometric Mean	Percentiles Selected			
			95% CI	50th	90th	95th
Total	1709	1.02	0.85-1.20	0.94	4.84	7.13
Age (years)						
16-19	513	0.63	0.49-0.76	0.58	2.47	3.28
20-29	437	0.87	0.68-1.06	0.79	4.79	6.43
30-39	405	1.09	0.84-1.35	0.97	5.07	8.95
40-49	354	1.32	1.04-1.60	1.24	5.31	7.13

Table 2. Blood Organic Mercury Concentrations (μg/L) for Women Ages 16-49 Years among the 1999-2000 NHANES Examinees (Mahaffey et al., 2004).

	Sample Persons	Geometric Mean	Selected Percentiles			
			95% CI	50th	90th	95th
Total	1707	0.80	0.34-0.66	0.60	4.44	6.73
Age (Years)						
16-19	513	0.49	0.40-0.58	ND	2.03	2.88
20-29	436	0.70	0.54-0.87	0.44	4.50	6.10
30-39	405	0.83	0.61-1.04	0.61	4.65	8.62
40-49	363	1.02	0.79-1.24	0.90	4.93	6.73

In the United States the Centers for Disease Control conducts the NHANES which provides medical examinations, biochemistry assessments for exposure to environmental contaminants, dietary and medical histories, clinical chemistry profiles, and a large number of other specialized tests to approximately 8,000 persons per year. This survey is conducted in approximately 25 to 30 communities per year and these communities are selected so that if treated by appropriate population statistics, the data can provide a profile that is representative of the United States as a whole.

Among adult women of childbearing age (considered being 16 years through 49 years) and young children ages one through six years (beginning with the years 1999 and 2000), biomarkers of mercury exposure were measured. These included hair mercury (total and inorganic), blood mercury (total and inorganic), and urinary mercury (total only and among adult women only). Organic mercury was calculated by differences and chemical speciation of samples indicated that the predominant chemical species was methylmercury (Schober et al., 2003; Mahaffey et al., 2004). Although adult men, children older than six years, and women older than 49 years were included among the NHANES examinees, mercury measurements were not included for the age and gender groups during the 1999 and 2000 years of the survey. These groups have been added beginning in 2003. Blood mercury concentration data are shown in Table 1 which indicates the geometric mean, 95% CI, 50^{th}, 90^{th} and 95^{th} percentiles for blood total mercury by age group. Organic blood mercury concentrations, almost entirely methylmercury, are shown in Table 2. Children in the age 1-to-6 year age range have much lower blood mercury concentrations than did the adult women. Table 3 shows hair mercury concentrations for adult women and children who were examinees in the 1999 and 2000 NHANES.

Table 3. Mean and Selected Percentiles of Hair Mercury (Hg) Concentrations for Children Aged 1-6 Years and Women Aged 16-49 years - National Health and Nutrition Examination Survey, United States, 1999 (McDowell et al., 2004).

			Selected Percentiles					
Hair Hg	No.	Mean (95% CI)	10^{th} (95% CI)	25^{th} (95% CI)	50^{th} (95% CI)	75^{th} (95% CI)	90^{th} (95% CI)	95^{th} (95% CI)
Children	838	0.22 (0.18,0.25)	0.03 (0.01,0.05	0.06 (0.05,0.07)	0.11 (0.10,0.13)	0.21 (0.15,0.27)	0.41 (0.33,0.49)	0.65 (0.52,0.76)
Women	1726	0.47 (0.35,0.58)	0.04 (0.02,0.05)	0.09 (0.07,0.11)	0.19 (0.14,0.24)	0.42 (0.29,0.55)	1.11 (0.54,1.68)	1.73 (1.44,2.02)

Surveys from Individual States

Analyses of blood and hair samples for mercury indicate a range of exposures present under localized conditions. The upper end of this exposure distribution

extends into concentrations reported to be 50 μg/L to 70 μg/L for blood; hair values occasionally > 10 ppm with average values typically in the 1 ppm to 3 ppm range. This information has been provided in detail in US EPA's Mercury Study Report to Congress (US EPA, 1997), Volume 4, Section 6.4.4 (blood mercury) and Section 6.5.2 (hair mercury). Blood mercury concentration was associated with increased consumption of fish, particularly species known to be high in methylmercury or species containing < 1 ppm mercury but consumed routinely.

More recent data are not dissimilar, although from geographically diverse areas. For example, hair mercury concentration of a group of 16 rural Alaskan subsistence food users from Napakiak, a small Yup'ik Eskimo in southwest Alaska was compared with a group of non-subsistence non-Yup'ik adults from the urban interior city of Fairbanks, Alaska (Rothschild and Duffy, 2002). The mean methylmercury concentration in hair for the Yup'iks was 1.45 ppm (range 0.32-4.00 ppm), which was higher than that of the Fairbank dwellers whose mean was 0.19 ppm (range 0.03 to 0.43 ppm). Pregnant women (mainly during their first trimester) from the eastern United States' State of New Jersey had hair and blood samples analyzed for total mercury (Stern et al., 2001). Between 85% and 90% of women had hair mercury levels < 1.0 μg/g, and 1% to 2% had values > 4.0 μg/g.

Exposures at the Higher End of the Continuum of the General Population in the United States and Territories

There is a continuum of exposure to mercury with higher exposures found among people with particular characteristics including geographic locations (e.g., island populations), ethnic groups with food habits which prefer fish (e.g., Asian populations), occupations (e.g., dentists, gold miners), and life styles (e.g., affluent patients who have been consuming a high-fish diet for promotion of cardiovascular health). These groups' mercury exposures will be quite different from those identified by either the NHANES data or general data reported in state surveys.

Data from the NHANES provide an estimate for the United States population. It may be important, however, that frequency of fish consumption - the primary determinant of methylmercury exposure - was not a selection factor for inclusion in the survey. This may or may not affect the validity of extrapolation of the NHANES data in making population estimates. The initial reports from 1999-2000 NHANES were based on 26 communities. Additional two-year cycles of the NHANES will add between 25 and 30 communities with each cycle. Currently the 2001/2002 data are being statistically analyzed and the

2003 and early 2004 samples have been completed with the 2004 survey underway.

These additional years of data from NHANES will strengthen our data base and provide greater ability to better describe subpopulations. Nonetheless, based on reports from case series, communities and medical practices, it is already known that much higher exposures to methylmercury in the United States have been documented than were identified among the 1999-2000 NHANES examinees. As physicians have become more aware of mercury as a health concern for the general population, obtaining mercury measurements on patients' blood samples have increased resulting in expanded awareness of the magnitude of mercury exposure in groups not typically considered to be at elevated risk of exposure to methylmercury.

Some health departments in the United States (e.g., the State of North Carolina) have begun to offer screening for blood mercury to people who may be concerned that their mercury exposures are elevated. For example, in Louisiana the State Office of Public Health began offering to measure blood mercury levels and reported screening values for 313 participants (Bellanger et al., 2000) whose blood values ranged from < 0.3 μg/l to 35 μg/L with 1.9% > 20 μg/L. Higher values were reported among commercial fishermen and their families. Blood mercury values were twice as high among people who ate fish at least once a week compared with people who ate fish twice a month or less. Elevated blood mercury concentrations have been found among gamefish consumers in Arkansas (Burge and Evans, 1994).

High blood mercury concentrations (e.g., > 80 μg/L) have been reported among high-income individuals who choose to consume diets that contain large amounts of fish in the view that such diets will be advantageous to their health. Others pursue these diets for culinary preference. For example, Hightower and Moore (2003) reported blood mercury concentrations from a private practice patient population in San Francisco. From a total of 116 patients evaluated, 89% had blood mercury concentration ≥5 μg/L, and 16% had concentrations ≥20 μg/L. Four individuals in this group had blood mercury levels more than 50 μg/L. Following the 2003 publication Hightower tested an additional 107 patients whose average blood mercury concentration was 21 μg/L (Hightower, 2004). Saint-Phard et al. (2004) reported a case series from University of Colorado in which patients with elevated blood mercury (range 27 μg/L to 96 μg/L) associated with fish consumption had neurological symptoms (i.e., including paresthesias of the extremities and or electrodiagnostic evidence of sensorimotor peripheral neuropathy).

In addition to these cases, other clinics and individual physicians have identified individuals with blood, hair, and urinary mercury values considerably higher than those reported among NHANES examinees. Among others see Kales

and Goldman (2002). In addition to methylmercury ingested from frequent consumption of fish containing high concentrations of methylmercury, other medical reports indicate exposures to inorganic mercury from folk remedies, cosmetics, gold smelting. It is important to know that the highest blood value reported from 1999-2000 NHANES was 35 μg/L of which only about 50% of the total mercury present was organic mercury (Mahaffey et al., 2004).

Residents of those states and territories of the United States (e.g., Hawaii, Puerto Rico) who have geographic proximity to a steady supply of fresh fish have greater intake of methylmercury than the more inland populations. For example, Ortiz-Roque and Lopez-Rivera (2004) investigated blood mercury concentrations and seafood consumption frequency among reproductive-age women in two areas of Puerto Rico.

Overall-United-States data from NHANES indicated 30-day consumption of fish and shellfish at the 50th percentile was 1.54 meals (95% CI: 1.25-1.82) and at the 90th percentile 10.81 meals (95% CI: 7.15-14.47) (Schoeber et al., 2003). Average Puerto Rican total seafood consumption was 12.1 meals/30 days in NE Puerto Rico and 21.2 meals/30 days in Vierques, an island municipality. That is to say that average Puerto Rican fish and shellfish consumption was higher than 90th percentile intake for the overall United States. The percent of women whose mercury intake exceeded the RfD was 6.6 in NE Puerto Rico and 26.8 in Vieques. Among Viequenses three of the 41 women had hair mercury concentrations higher than 12 ppm which is the lower bound of the benchmark dose for mercury, an effect level (Ortiz-Roque and Lopez-Rivera, 2004).

Canada

Northern Canada

Canadian data on mercury exposure can generally be separated into studies of northern Canada and studies from more southern Canadian regions. A comprehensive review of the Arctic studies by Van Oostdam et al. (1999) provided an in-depth analysis of the cultural and nutritional significance of wildlife as food for indigenous people, as well as a consideration of a range of contaminants including organochlorines, heavy metals, and radionucleides. A monitoring program providing data on mercury levels among the Cree population of James Bay, Quebec in 1988 and in 1993/1994 indicated that the proportion of the Cree population with total hair mercury concentrations > 15.0 μg/g decreased from 14.2% in 1988 to 2.7% in 1993/1994 (Dumont et al., 1998).

Inuit inhabitants of northern Canada in a region called Nanavik consume in their traditional diet large amounts of marine foods. Muckle et al. (2001) reported

cord blood, maternal blood, and maternal hair mercury concentrations averaged 18.5 μg/L, 10.4 μg/L, and 3.7 μg/g. Time trends in cord blood mercury reported by Dallaire et al. (2003) describe concentrations of Inuit infants born between 1994 and 2001, indicate mean cord blood concentrations declined from approximately 20 μg/L in 1993 to approximately 8 μgl/L in 1999. This decrease does not appear to depend on a decline in fish consumption based on ω-3 fatty acid level, an indicator of fish intake.

Southern Canada

Reports on blood and hair mercury concentrations in southern Canada indicate much lower mercury exposures in general than observed in northern Canada (see Table 4).

Rhainds et al. (1999) data on newborns' after adjustment of mercury concentration for differences in the cord blood to maternal blood ratio using 1.7 to 1.0 (Sterns and Smith, 2003) indicated maternal blood mercury concentrations averaged < 1 μg/L. Comparing regions of Quebec, blood mercury concentrations were associated with residency area with coastal > urban > suburban > rural. Morrissette et al. (2004) identified a similar exposure range for women early in pregnancy. Speciation of blood samples indicated about half of the mercury in blood at this exposure range was inorganic mercury.

Table 4. Mercury Concentrations (μg/g wet weight) in Traditional Foods Consumed by Canadian Aboriginal Peoples (modified from Chan, 1998).

Food Group	Number of Sites	Number of Samples	Arithmetic Mean	Standard Deviation	Maximum
Marine Mammal Meat	32	764	0.85	1.05	33.4
Marine Mammal Blubber	6	71	0.08	0.05	0.13
Terrestrial Mammal Meat	6	19	0.03	0.02	0.17
Terrestrial Mammal Organs	14	254	0.86	0.90	3.06
Fish	799	31,441	0.46	0.52	12.3
Birds	24	216	0.38	0.59	4.4
Plants	8	14	0.02	0.02	0.05

Mahaffey and Mergler (1998) found that increased consumption of lake fish was associated with higher blood mercury concentrations among 289 residents of Southwest Quebec, but with one exception total blood mercury concentrations

were < 5 μg/L. One individual, however, had a blood mercury concentration of ~70 μg/L greatly exceeding all of the other subjects.

Among groups who consume sports fish, methylmercury exposures are somewhat higher. Kosatsky et al. (2000) compared blood mercury concentrations among those who ate sports fish at least once a week and reported a geometric mean blood mercury concentration of 3.03 ±2.43 μg/L compared with blood mercury of 1.44±2.23 μg/L for those eating sports fish less than once a week. The highest blood mercury concentrations were associated with consumption of high-food-chain piscivorous fish.

The wide variation in blood mercury concentrations, however, indicates some consumers of fish with higher mercury levels. Hair mercury concentrations also reflected these differences. Evaluation of the patterns of fish consumption among the sports fishers (Kosatsky et al., 2000) showed a strong correlation between blood mercury and hair mercury. A small group of sports fishers of recent Asian immigration (from Vietnam and Bangladesh) had higher hair mercury concentrations than the high-level, native-born Canadians (Kosatsky et al., 1999b).

Brazil

Amazon River Basin and Tributaries

Widespread use of mercury to amalgam gold by miners in the Amazon River Basin and its tributaries over past decades has resulted in severe contamination with inorganic mercury. The process of producing a mercury-gold amalgam and using torches to drive off the mercury in open air with no worker protection has resulted in severe mercury poisoning among miners. The condensed mercury vapor and inorganic residue are then dumped into the Amazon River Basin and its tributaries. This topic is covered in detailed reviews by many others including Eisler (2004).

To summarize briefly twenty-five years of significant data on the impact of use of mercury in gold mining and its impact on the people living in the region, hair mercury concentrations among riparian river people are highly elevated, but variable depending on the amount and species of fish consumed. Seasonal variation is also found because the species of fish that are available changes with the season (Dolbec et al., 2001).

Mean or median hair mercury concentrations between 2 μg/g and 20 μg/g have been reported (Akagi et al., 1995; Barbosa et al., 1998; Lebel et al., 1998; Dolbec et al., 2000). Harada et al. (2001) evaluated three fishing villages located several hundred kilometers downstream from the gold mining areas. Eighty

percent of subjects had hair mercury concentrations > 10 ppm. Similar exposures are reported by Dorea et al. (2003) who evaluated adult women of childbearing age living in locations of the Rio Negro basin that were not impacted by gold mining. These women consumed an estimated fish intake of 170 grams per day.

The mean mercury concentration in the individual fish species varied between 0.04 and 0.59 μg/g, but 27% of samples had concentrations > 0.50 μg/g and 7% were > 1.00 μg/g. The women's hair mercury concentrations ranged between 6.5 and 32.6 μg/g, with 82% of women's values > 10 μg/g.

Sing et al. (2003) have studied Yanomama Indian villagers living near mined and unmined rivers beginning in 1994. Re-evaluating these villagers indicated average blood mercury concentration between 21.2 μg/L and 43.1 μg/L. Mercury concentrations in piscivorous fish (piranha) from the mined Catrimani River ranged from 0.23 to 1.08 ppm. High mercury concentrations were also observed in fish and villagers along the unmined Ajarani and Pacu Rivers.

Santos et al. (2002) conducted a cross-sectional study among the Munduruku Indians living in the State of Para, Brazil. Mean hair mercury concentrations were 14.4 μg/g for children aged 7 to 12 years, 15.7 μg/g for women aged 14 to 44 years, and 14.1 μg/g for all other people. Although the mercury concentrations of the fish were < 0.5 μg/g, the amount of fish consumed resulted in hair mercury concentrations for the women of childbearing age being higher than considered without risk by the World Health Organization 1990.

Hair mercury in these Amazonian fish-eating populations has been chemically speciated between inorganic mercury and organic mercury. In a Negro River fish-eating population who consumes fish at least twice a day, total hair mercury ranged from 1.5 μg/g to 59.0 μg/g (Barbosa et al., 2001). The mean percentage of methylmercury was 71.3% (range 34% to 100%) of total mercury in hair. The percent methylmercury was comparable across age and sex groups. Among women of reproductive age, 65% had hair mercury concentrations > 10 μg/g.

Other Regions of Brazil

Regions of Brazil away from the Amazon have reported far lower mercury exposures. For example, a coastal region of Brazil was evaluated because of possible mercury contamination due to a chlor-alkali plant installed along one of the tributaries of the channel (Nilson et al., 2001). Hair mercury concentrations in this area were 1.9 μg/g total mercury and 1.2 μg/g methylmercury. Local fish contained 0.026 total mercury and 0.019 methylmercury.

Argentina

Study of mercury in marine mammals in coastal waters indicates mercury contamination (Marcovecchio et al., 1994). Importance of local sources of contamination illustrated by the distribution of mercury from a mercury cell chlor-alkali factory that had operated for more than 40 years and dischaged plant effluents near the main irrigation channel for agricultural land showed accumulation of mercury in river bed sediments (Arribere et al., 2003).

Bolivia

Higher hair mercury concentrations among examinees in Japanese immigrant settlements in Bolivia compared with other groups in Brazil and Paraguay related to higher fish consumption among the Japanese immigrants (Tsugane and Knodo, 1987).

Chile

An overview of mercury contamination in Chile is recently available (Barrios-Guerra, 2004) that includes a description of industrial sources of mercury in Chile. Hair mercury concentrations among 59 pregnant and nursing women with normal to high fish and seafood consumption living in fishing villages distributed throughout the coastal zone of Chile were compared with an inland Chilean town (Bruhn et al., 1994). Total hair mercury content of the women in the coastal villages was 2.0± 1.4 μg/g compared with the control group's mean value of 0.4 ± 0.2 μg/g.

French Guiana

An investigation of 500 individuals from 13 health centers indicated that consumption of methylmercury from fish consumption (especially freshwater fish) in diet played a predominant role in the total mercury burden and that in some communities hair mercury concentrations exceeded 10 μg/g (Cordier et al., 1998). In their overall sample 12% exceeded 10 μg/g, but in some Amerindian communities up to 79% of the children had hair mercury concentrations > 10 μg/g. These investigators also identified some high exposures to inorganic mercury associated with use of mercury for religious rituals.

SOURCES OF MERCURY EXPOSURE

Mercury in Foods and Products

Chemical species of Mercury

Methylmercury is bound to the amino acids in fish muscle and cannot be removed by food preparation or cooking (Morgan et al., 1997). Estimates of exposure to mercury through diet can be determined by chemical analyses of food (Gunderson, 1995; Larsen et al., 2002; Nakagawa et al.; 1997; Sanzo et al., 2001; Urieta et al., 1996; Ysart et al., 2000). Within the diet consumed by populations who do not include marine mammals in their diets (marine mammals are discussed separately below), fish and shellfish contain the highest mercury concentrations (Larsen et al. 2002; Urieta et al., 1996; Ysert et al., 2000), although trace amounts of total mercury may be detected in other dietary components (e.g., eggs, organ meats such as kidney (Larsen et al., 2002), or offal (Ysart et al., 2000). Diets are usually analyzed for total mercury without chemical speciation to differentiate between organic mercury, specifically methylmercury, and inorganic mercury. Based on total diet data for the United States, in which only total mercury is measured routinely, mercury is identified consistently only in the fish and shellfish components of diet. MacIntosh et al. (1996) indicated that dietary mercury exposures at the upper end of the established distribution for approximately 120,000 adults were dominated by the consumption of fish products (87% of total mercury intake), principally canned tuna (65%), in the Nurses' Health Study and Health Professional Follow-Up Study. The organic mercury in fish and shellfish has been repeatedly speciated and is methylmercury (Bloom, 1992; Falter and Scholer, 1994; Haxton et al., 1979; Kannan et al., 1998).

Mercury present in fish is approximately 85% methylmercury and higher for fish muscle (e.g., Storelli et al.; 2000, 2002). In nonmuscle tissues (e.g., organs such as kidney or liver), the fraction of total mercury that is methylmercury is substantially less than 80% to 90%. The fraction of mercury in shellfish that is methylmercury varies even within a species. For example, Ipolyi et al. (2004) found that the percent methylmercury in mussels varied between 33% and ~ 90%.

Mercury Concentrations in Fish and Shellfish. Mercury concentration in fish is determined by the feeding habits of the fish, the mercury concentration in tissues of its prey, the fish's age, and place in the food chain. Some highly migratory species such as tuna appear to be more consistent in their mercury concentration at a particular age and size than do species that remain in a much

more restricted geographic range that can be more readily influenced by local conditions. Reference to some of the larger or more detailed data sets on mercury concentrations in fish and shellfish includes the following for particular countries in the Americas:

USA	Bahnick et al., 1994 Hall et al., 1978 Adams and McMichael, 2001
Canada	Jensen et al., 1997 Canadian Arctic Contaminants Assessment Report Chan, 1998 Data Base for Environmental Contaminants in Traditional Foods
Brazil	Bidone et al., 1997 Tapajós River Basin, Pará Boischio and Henshel, 2000 Madeira River Dolbec et al., 2001 Tapajós River Basin, Pará Dos Santos et al., 2000 Tapajós River Basin, Pará Niercheski et al., 1997 Patos and Mirim Lagoons Passos et al., 2003 Tapajós River Basin, Pará

The concentration of methylmercury in fish and shellfish species ranges from < 0.1 ppm for shellfish species to > 1 ppm for high-end predatory fish including ocean fish [such as tuna (Storelli and Marcotrigiano, 2000), marlin (Schultz et al., 1976), and sharks (Penedo de Pinho et ala., 2002)] and freshwater fish [e.g., walleye and northern pikes (Gilmour and Riedel, 2000; Jewett et al., 2003)]. Consequently mercury intake depends on the species of fish consumed, as well as the quantity of fish eaten.

Mercury in Marine Mammals. Most of the traditionally harvested fish and land/marine mammals consumed by the northern Canadian indigenous peoples are long-lived and are from the higher trophic levels of the food chain which contain greater concentrations of methylmercury than are found in nonpredatory fish (Jensen et al., 1997). Several extensive data sets on mercury concentrations in marine mammals consumed by indigenous populations living in the circumpolar regions have been published (Wagemann et al., 1996 and 1998; Caurant et al., 1996; Dietz et al., 1996). Analyses that determined chemically speciated mercury have shown that mercury present in muscle tissue is largely (>75%) organic mercury (i.e., methylmercury) (Caurant et al., 1996). By contrast, mercury present in organs such as liver and kidney is predominantly in an inorganic form (Caurant et al.,1996). Traditional diets of indigenous peoples

living in northern communities differ from one another (e.g., Dene Communities in contrast with Inuit Communities) with substantial differences in their methylmercury content (Table 5). Jensen et al. (1997) in the *Canadian Arctic Contaminants Assessment Report* identified wide variability in the consumption of fish and marine mammals by various aboriginal groups.

Table 5. Estimated Daily Intake of Mercury Using Contaminant Data Base and Dietary Information from Dene and Inuit Communities in Canada (adapted from Chan, 1998).

Food Group	Dene Community		Inuit Community	
	Food (g/day)	Mercury (µg/day)	Food (g/day)	Mercury (µg/day)
Marine Mammal Meat	0	0	199	170
Marine Mammal Blubber	0	0	30	2
Terrestrial Mammal Meat	205	6	147	4
Terrestrial Mammal Organs	23	20	1	1
Fish	80	13	1	1
Birds	8	1	2	1
Plants	2	0	2	0
Total	318	40	423	185

Quantity of Fish, Shellfish and Marine Mammals Consumed Dietary intakes of fish and shellfish are enormously variable across countries in the Americas ranging from no intake to several hundred grams per day.

Consumption of marine mammals appears limited to indigenous peoples living in circumpolar regions. Even within the population of one country, fish and shellfish consumption vary substantially. In the United States less than 15% of the population consumes fish or shellfish on a weekly basis, yet a few percent of people consume fish several times a week. In the Amazon region whose riverine population's mercury exposure has been documented, the fish consumption of the urban areas has also been found to be substantial. Giugliano et al. (1978 - *cited in* Boischio and Henshel, 2000) estimated daily fish consumption per capita to be approximately 100 to 150 grams of fish among an urban population based on 1200 households in Manaus, Amazonas. However, the species of fish consumed differed from those of the riverine peoples.

An analysis of the patterns of fish species consumed (herbivores, omnivores, phanktophagus, piscivore) and the mercury concentration of these species has been used to predict mercury exposure for the Madeira River people by Boischio

and Henshel (2000).

Table 6. Hair and Blood Mercury Concentrations in Southern Canadians.

Group	Reference	Findings
During 1993 to 1995 10 hospitals in southern Quebec monitored umbilical cord blood samples from 1109 newborns.	Rhainds et al., 1999	Mean mercury in cord blood 4.82 nmol/L (CI 4.56-5.08) or 0.96 ug/L. Using a cord:maternal ratio of 1.7:1.0 and converting to µg/L this corresponds to a maternal mercury concentration of 0.56.
Montreal area sports fishers with fish consumption of 18.3 kg/yr of sports fish vs. reference group consuming 3.3 kg/yr of sports fish.	Kosatsky et al., 1999a	Hair mercury median concentration of 0.73 µg/g for sports fishers (n=25). Highest value, 4.4 ppm. Vs. 0.23 µg/g (n=15). Highest value 0.82 µg/g.
St. Lawrence River fish consumers of Asian origin (Bangladeshi and Vietnamese) and a reference group of high-level sports fish consumers.	Kosatsky et al., 1999b	Hair mercury concentrations for Vietnamese males (n=9). Median 1.23 µg/g, 90th percentile 4.62 µg/g, and Bangladeshi males, median 1.07 µg/g, 90th percentile 2.29 µg/g, and high-end sports fish consumers, median 0.73 µg/g, 90th percentile 1.88 µg/g.
St. Lawrence River sportsfish consumers comparison between those who ate sports fish at least once a week and those eating sports fish less than once weekly.	Kosatsky et al., 2000	Persons consuming sports fish at least once a week (n=60). Hair mercury geometric mean, 0.82±2.54 µg/g and blood mercury geometric mean of 3.03 ±2.43 µg/L. Consuming sportsfish < once/week (n=72) hair mercury geometric mean 0.38±2.38 µg/g and blood Hg of 1.44±2.23 µg/L. Persons consuming sports fish 2 or more times/week
Population in Southwest Quebec living near the Upper St. Lawrence River System..	Mahaffey and Mergler, 1998	Increased consumption of lake fish associated with higher blood mercury among 289 residents. Total blood Hg < 5 µg/L except for one individual with a blood Hg of 70 µg/L.
Pregnant women living along the St. Lawrence River. 1st trimester of pregnancy. Market fish were the source of mercury exposure.	Morrissette et al., 2004.	First trimester of pregnancy (n=39). Total blood Hg. Geometric mean (GM): 0.85 µg/L. Arithmetic mean (AM)= 0.99 µg/L. 5th - 95th, 0.40-2.20 µg/L. Organic blood Hg. GM: 0.36 µg/L. AM: 0.48 µg/L 5th - 95th: n.d. - 1.20 µg/L Inorganic blood Hg GM: 0.45 µg/L AM: 0.51 µg/L 5th - 95th: n.d. - 1.80

Among the fish species described mean mercury concentrations ranged from 0.06 ppm to 1.44 ppm. In most of the Amazonian studies, piscivorous fish species have mercury concentrations > 0.5 ppm (Lodenius and Malm, 1998).

Other estimates of fish intake in Amazonia provided by Boischio and Hensel (2000) ranged between 90 grams/day and 370 grams/day. In view of the wide range in quantities of fish consumed and differences in the mercury concentration in the fish, it is more informative to consider the data on hair and blood mercury concentrations reported from Amazonian communities.

Cosmetics

Use of "beauty" and skin-lightening creams or lotions have been reported worldwide [e.g., Sin and Tsang (2003) from Hong Kong; Al-Saleh et al. (2003) from Saudi Arabia; Adebajo 2002 from Nigeria]. These include various "beauty" lotions containing inorganic mercury which are also found in the Americas. One product has been well described and found to contain between 6% and 10% mercury by weight (Balluz et al., 1997), was distributed across the Mexican-US border, and was associated with an increase in urinary excretion (Weldon et al., 2000) of inorganic mercury to levels > 100 μg/L (reference range: 0 to 20 μg/L) among users of this product which contained "calomel" or mercurous chloride [Hg_2Cl_2] (CDC, 1996). These products are commonly available. For example the Mexican Secretary of Health seized 35,000 containers of this product in one state in Mexico (CDC, 1996).

In the United States mercury compounds can only be used as preservatives in eye-area cosmetics at concentrations not exceeding 65 ppm mercury (CDC 1996). Balluz et al. (1997) point out that standards for production and regulation of cosmetic products vary worldwide. Ingredients that are restricted in one country may be entirely legal in another.

Dental Amalgams

An alloy of silver, copper, tin and 50% inorganic mercury has been used in dental practices as a restorative material to fill teeth. Mercury released from these amalgam fillings occurs in multiple forms: elemental mercury vapor, metallic ions, and/or fine particles. Results indicate that placement of mercury-containing amalgams in teeth result in an increased body burden of mercury in body tissues (US DHHA, 1993; Henderson, 1995; Weiner and Nylander, 1993). Barregard et al. (1995) and Francis et al., (1982) indicate that individual variation in habits can influence the amount of mercury released from mercury

amalgams including bruxism and gum chewing.

The controversy regarding whether or not mercury from silver-mercury amalgams produces adverse health effects has been a topic for more than 150 years and has been the subject of a substantial literature including more than 110 review articles based on a search of Pub Med. Among many others see Ekstrand et al. (1998), Dunne et al. (1997), Eley (1997a and b), and Jones et al. (1999). Currently a clinical trial is underway (Children's Amalgam Trial Study Group, 2003) to investigate the effect of amalgam restorations on change in IQ scores and other neuropsychological assessments and renal functioning.

There is a consensus, however, that dental workers need to be protected from exposure to mercury vapors in dental clinics (Chang et al., 1992). Dental associations have provided practice information to provide guidance to dentists and their staff members for safe handling of mercury and dental amalgam (ADA Council on Scientific Affairs, 2003). Guidance is also provided to reduce release of mercury from dental offices into the environment.

Drugs, Biologicals and Folk Remedies

Drugs and Biologicals

Ethylmercury under the trade name thimerosal has been used as a preservative in vaccines since the 1930s (Midthun, 2004) and biological products (ophthalmic solutions, optic suspension, creams) for at least a century. Many vaccines contained a preservative because they were marketed for use in multi-dose vials. Mercury exposures via this route of administration differ because these are administered by injection resulting in a high, bolus dose producing a high blood mercury concentration. Beginning in the mid-1990s in the United States there has been an intense controversy regarding the neurodevelopmental effects of greater exposure to ethylmercury in vaccines as part of an accelerated immunization schedule for infants. This controversy continues. The most recent health assessment was reported from the United States National Academy of Sciences' Institute of Medicine (NAS, 2004). A neurodevelopmental follow-up study is underway in Italy with resulted expected in 2006 (Wharton, 2004).

Thimerosal has been removed from a large number of vaccines (CDC, 1999). It should be noted, however, that mercury continues to be used in biologicals sold in the United States and quite likely also in other countries in the Americas. Mercury containing ingredients currently used in biologics in the United States include thimerosal, phenylmercuric acetate, phenylmercuric nitrate, mercuric acetate, mercuric nitrate, merbromin, and mercuric oxide (http://www.fda.gov/

cder/ fdama/mercury300.htm). This information was derived from submissions made in response to the Food and Drug Administration Modernization Act of 1997 which required US FDA to review the risks of all mercury-containing food and drugs. These products include vaccines, ophthalmic solutions, nasal sprays, and immune globulins.

Sanitizers and Antifungals

Phenylmercury compounds are part of a broad class of aryl and alkoxyl aryl mercurials that have been used world wide as disinfectants and fungicides (Gotelli et al., 1985). A massive exposure to infants was discovered in Buenos Aires in 1980 following use of phenylmercury by a commercial diaper service. Urinary mercury concentrations for the exposed infants were 20-times higher than the control infants and inorganic mercury accounted for more than 90 % of the total mercury (Gotelli et al., 1985). Zaidi et al, (1995) reported mercury compounds included as disinfectants in hospitals in the state of Yucatan , Mexico. Use of phenylmercuric borate (0.04%) along with hexachlorophene as a hand disinfectant in soap resulted in increased urinary mercury compared with control subjects. It was concluded that the absorption of mercury from the phenylmercuric borate-containing soap occurred partly by transfer from the hands to the oral cavity (Peters-Haefeli et al., 1976).

Organo-mercurial Pesticides

Although these are banned from commerce, use of mercury compounds in farming may continue (Camara and Corey, 1994). For example, the Ministry of Agriculture/Plant Health Protection banned the use of all mercury-containing compounds in Brazil in 1980, however, the importance has been emphasized for continuance of programs for surveillance, particularly for problems arising as a result of accidents or from the importation, production, sale, and uses of officially banned products (Camara and Corey, 1994).

Miscellaneous sources of inorganic mercury

Ingestion of small quantities of elemental mercury is commonly reported to poison control centers. For example, nearly 3,000 cases of mercury exposure were reported to the American Association of Poison Control Centers Toxic Exposure Surveillance System in 1996 (Litovitz et al., 1996). However,

elemental mercury may be deliberately ingested. Elemental mercury is part of various folk remedies, particularly for gastroenteritis (Geffner and Sandler, 1980), and may produce medial complications depending on the quantity ingested (McKinney, 1999).

In the Americas ethnic and folk uses of mercury are associated with cultural practices known as "Santeria," "Espiritismo" and "voodoo." Santeria, for example, is a religion that developed in Cuba from the sixteenth to the nineteenth century as a syncretism of African religions, Roman Catholicism, and French spiritism (Lefever, 1996). It's practice and beliefs have been transferred to many communities in the Americas including the United States. Espisitismo is a spiritual belief system indigenous to Puerto Rico and other Caribbean islands (Bird and Canino, 1981). Mercury in the form of metallic mercury (Forman et al., 2000) is sold in botanicas, stores that specialize in selling religious items used in Espiritismo, voodoo, and Santeria (Zagas and Ozuah, 1996). Mercury is used in several ways: carried in sealed pouches, sprinkled in the home, carried in pockets, sprinkled in the car, or consumed in small quantities (Zayas and Ozuah, 1996). A cluster of cases in New York has been described in which vapors of metallic mercury from mercury to be used in mercury -filled ampulets prepared for practioners of Santeria were the source of elevated urinary mercury levels (US EPA, 2002; Forman et al., 2000). The extent of this practice is not known. In the United States analyses for inorganic mercury is now being included in housing surveys in addition to inorganic lead used to identify lead-based paints.

Spills of inorganic mercury occur in homes from accidents, measuring devices in homes (e.g., gas meters), and deliberate contamination. The actual number is unknown. An analysis of the number that were reported to hazardous substance authorities was provided by the Agency for Hazardous Substances and Disease Registry (ATSDR) in 2002 (Zeitz et al., 2002). Reporting on 406 events that occurred between 1993 and 1998 in which mercury was the only substance released, there were reports of adverse health effects and elevated blood mercury levels in some individuals. Evacuations were ordered in 22% of the spills causing an economic and public health impact.

Occupational

Mining

In the Americas Artisanal gold mining typically encompasses small, medium, informal, legal, and illegal miners who use rudimentary processes to extract gold ore (Veiga, 2004). The number of Artisanal gold miners in Latin America is

estimated to be between ~ 500,000 and just over 1 million who mine between 115 and 188 tonnes of gold annually Table 7 (Veiga, 1997).

Although use of mercury in mineral processing is illegal in most countries, mercury amalgamation is the preferred method employed by small Artisanal miners (Veiga, 2004). Mining operations expose miners directly to mercury vapor from burning of mercury amalgam or gold burning to separate gold from mercury. Secondary exposures to methylmercury from consumption of locally obtained fish contaminated with methylmercury incorporated from mercury discharged into the environment effects miners and the entire community. Consequently the number of people impacted by the mining operations exceeds the number directly involved in mining.

Table 7. Artisanal Gold Miners in Latin America from Veiga (1997).

Country	Gold (tonnes)	Number of Miners
Brazil	30 - 50	200,000 - 400,000
Colombia	20 - 30	100,000 - 200,000
Peru	20 - 30	100,000 - 200,000
Ecuador	10 - 20	50,000 - 80,000
Venezuela	10 - 15	30,000 - 40,000
Suriname	5 - 10	15,000 - 30,000
Bolivia	5 - 7	10,000 - 20,000
Mexico	4 - 5	10,000 - 15,000
Chile	3 - 5	6,000 - 10,000
French Guyana	2 - 4	5,000 - 10,000
Guyana	3 - 4	6,000 - 10,000
Nicaragua	1 - 2	3,000 - 6,000
Dominican Republic	0.5 - 1	2,000 - 3,000
Others	2 - 5	6,000 - 15,000
Total	115.5 - 188	543,000 - 1,039,000

Inorganic mercury is not strongly absorbed through the skin and is minimally absorbed from the gastrointestinal tract. The exposure danger is through inhalation of mercury vapor as the gold-mercury amalgam is retorted or simply burnt openly in pans. Specifics on the methods of retorting and reducing exposures are covered by Veiga (2004).

The gold *doré* that results when the amalgam is retorted rather than burnt is sold in villages to gold shops that melt the gold *doré* to rid it of its impurities. This *doré* contains mercury impurities that are then released into gold shops and distribute mercury vapors into the urban atmosphere (Veiga, 2004).

Chloralkali Factories

The chlor-alkali electrolysis process produces chlorine, hydrogen and sodium hydroxide (caustic) solution. In some countries chlorine is the product of commercial importance and is used as a bleaching agent for the textile and paper industries and for general cleaning and disinfection. Since the 1950s, chlorine has become an increasingly important raw material for synthetic organic chemistry and is an essential component of a multitude of end products. Plants utilize either the diaphragm cell process or mercury cell process. The environmental concern with these plants is release of mercury emissions from the plants, so called "fugitive sources" (Lecloux, 2003; Wangberg et al., 2003; http://www.epa.gov/ttn/oarpg/) and in particular identification of the atmospheric mercury species/fractions measured in the plume from the chlor-alkali plant emissions.

Smith et al. (1970) conducted an extensive assessment of 642 workers in 21 chloralkali plants in the United States and Canada. Time weighted average exposures to mercury ranged from near zero to 270 $\mu g/m^3$ with 85% of the group $\leq 100\ \mu g/m^3$. When exposures exceeded 100 $\mu g/m^3$ symptoms included loss of appetite and weight, tremors, insomnia, and other indicators of early effects on the nervous system. Even among controls urinary mercury concentrations were much higher than general population values reported in current values (i.e.,United States, non-occupational, post 2000). Approximately 65% of the control group had urinary mercury concentrations > 10 µg/L. Worker values exceeded 1,000 µg/L for 7% to 8% of subjects.

Reports from other countries indicate neurological and renal effects of exposure to inorganic mercury and mercury vapor. Specifically cerebral effects of long-term exposures to mercury vapor (Pikivi and Tolonen, 1989) are shown by abnormalities in electroencephalography. Increased urinary excretion of renal enzymes has been found in chlor-alkali workers exposed to inorganic mercury compared with age-matched controls when urinary mercury values averaged 35 µg/g creatinine (Barregard et al., 1988). Albers et al. (1982) have described plyneuropathy among chlor-alkali plant workers chronically exposed to inorganic mercury vapor. They concluded that elemental mercury exposure was associated with a sensorimotor polyneuropathy of the axonal type and that the degree of neurologic impairment appeared related to the magnitude of mercury exposure.

A number of chlor-alkali factories have been closed. For example, in the United States a 1992 report indicated 52 chlor-alkali plants in operation in 23 states (US EPA, 1992).

In the announcement of the final rule to reduce toxic air pollutants from mercury cell chlor-alkali plants, there were nine facilities located in eight states (

http://www.epa.gov/ttn/oarpg/t13/fact_sheets/mccap_fs.pdf). However, closed chlor-alkali plants can continue to release inorganic mercury into the environment over time. An environmental assessment in the Upper Negro River valley area in Argentina in the vicinity of a closed chlor-alkali plant (Arribére et al., 2003) indicated, however, that because the drainage areas near the plant had not become permanently flooded biomagnitication of mercury in the food chain was not occurring.

Other Industries

Industries in which occupational exposure to mercury may occur include chemical and drug synthesis, hospitals, laboratories, instrument manufacture, and battery manufacture (USA, National Institute for Occupational Safety and Health, 1977). Jobs and processes involving mercury exposure include manufacture of measuring instruments (barometers, thermometers, etc.), mercury arc lamps, mercury switches, fluorescent lamps, mercury boilers, mirrors, electric rectifiers, paints, explosives, photographs, disinfectants, and fur processing. Occupational mercury exposure can also result from the synthesis and use of metallic mercury, mercury salts, mercury catalysts (in making urethane and epoxy resins) mercury fulminate, Millon's reagent, pharmaceuticals, and antimicrobial agents [USA (Occupational Safety and Health Administration (OSHA, 1989)]. Within the USA Campbell et al. 1992 reported that about 70,000 workers are annually exposed to mercury. Inorganic mercury accounts for nearly all occupational exposures with airborne elemental mercury vapor the main pathway of concern in most industries, in particular those with the greatest number of mercury exposures.

SUMMARY

Mercury exposures in the Americas are highly varied ranging from analytically non-detectable to very high levels producing clinical poisoning. Methylmercury is the dominant chemical form of mercury for people who consume fish and shellfish. Who within the population consumes a high percentage of their dietary protein from fish/shellfish differs with social, economic, cultural and geographic conditions. The highest exposures to methylmercury in the Americas have been found among affluent, urban dwellers who consumed fish in pursuit of health (Hightower and Moore, 2003), among remote villagers in the Amazon who have an environment in which the fish are seriously contaminated with mercury (Dolbec et al., 2001), and among Inuit

villagers who consume marine mammals (Chan, 1998; van Oostdam et al., 1999) as part of their cultural traditions.

Among the general population of countries ranging from Canada to the USA to Chile exposure to methylmercury depends on both the quantity and species of fish consumed. General population survey data are available only for the United States and these data indicate that for the overall general population, 9% of women of childbearing age consume fish weekly (Mahaffey et al., 2004). Within the general population, approximately 3% of women consume fish daily. Groups at greater than average risk of methylmercury exposure from routine consumption of fish are persons of Asian or island ethnicity, coastal and/or island populations, individuals following "health" promoting diets, and some indigenous tribal groups. Their higher methylmercury exposure results from the greater overall quantities of fish consumed and/or the consumption of fish with relatively high mercury concentrations.

Within regions such as the Amazon having wide-spread mercury contamination secondary to release of inorganic mercury from mining operations, elevated mercury exposures with hair mercury concentrations frequently exceed 10 ppm hair mercury. In these regions choice of fish species to minimize mercury intake has been shown (Dorea et al., 2003; Passos et al., 2003) to be a possible means of reducing methylmercury exposures in a region where fish is the main routinely available source of protein.

Non-occupational inorganic mercury exposures, for the portion of the population who experience these, occur from mercury released from dental amalgams. Occupational exposures to inorganic mercury include persons working in dental professions, the chlor-alkali industry, and fluorescent bulb production and recycling. Statistics on the number of workers employed in the Americas in occupations that utilize mercury need to be summarized.

Far higher exposures to mercury vapor occur among artisanal miners, their families, and in communities associated with gold mining and gold ore processing. These exposures have been reported to be of a magnitude that produces overt clinical toxicity within a few months to a few years. Because of contamination of the surrounding ecosystems with mercury-laden waste from these mining operations, vast geographic areas surrounding mining activities have been grossly contaminated with mercury. Elevated mercury levels in the food chain result. Because people engaged in mining also may consume fish in their diets, a combined methylmercury and inorganic mercury pattern of exposure has been documented in Latin American countries.

Against this substantial background of methylmercury and inorganic/mercury vapor exposures, there are far less common exposures to organo-mercurials including phenylmercury and ethylmercury. Such compounds are found in "beauty" preparations, creams, topical preparations to treat skin conditions.

These compounds have produced poisoning among the unwary.

Biomonitoring of mercury concentrations in blood, hair, and urine are used to identify the magnitude and patterns of mercury exposure. Combined with dietary, occupational, cultural, and socio-demographic data such information can be used to identify sources of mercury exposure for individuals and populations. Such information can provide governments, public health authorities, medical organizations, physicians, and individuals with the links to stop or reduce exposures to mercury and mercurial compounds.

DISCLAIMER

The statements in this publication are the professional views and opinions of the author and should not be interpreted to be the policies of the United States Environmental Protection Agency.

REFERENCES

ADA Council on Scientific Affairs. Dental mercury hygiene recommendations. *J. Am. Dent. Assoc.*, 134, 1498-9, 2003.

Adams, D.H., McMichael, R.H. Mercury levels in marine and estaurine fishes of Florida. Florida Marine Research Institute Technical Report. TR-6. 35 pp. 2001.

Adebajo, S.B. An epidemiological survey of the use of cosmetic skin lightening cosmetics among traders in Lagos, Nigeria. *West Afr. J. Med.*, 21, 51-5, 2002.

Akagi, H., Malm, O., Kinjo, Y., Harada, M., Branches, F.J.P., Pfeiffer W.C., Kata, H. Methylmercury pollution in the Amazon, Brazil. *Sci. Tot. Env.*, 175, 85-96, 1995.

Albers, J.W., Cavender, G.D., Levine, S.P., Langolf, G.D. Asymptomatic sensorimotor polyneuropathy in workers exposed to elemental mercury. *Neurology*, 32, 1168-74, 1982.

Al-Saleh, I., Khogali, F., Al-Amodi, M., El-Doush, I., Shinwari, N., Al-Baradei, R., Histopathological effects of mercury in skin-lightening cream. *J. Environ. Pathol. Toxicol. Oncol.*, 22, 287-99, 2003.

Al-Shahristani, H., Shihab, K.M. Variation of biological half-life of methylmercury in man. *Arch. Environ. Health*, 28, 342-344, 1974.

Arribere, M.A., Ribeiro Guevara, S., Sanchez , R.S., Gil, M.I., Roman Ross, G., Daurade, L.E., Fajon, V., Horvat, M., Al Calde, R., Kestelman, A.J. Heavy metals in the vicinity of a chlor-alkali factory in the Upper Negro River ecosystem, Northern Patagonia, Argentina. *Sci. Tot. Env.*, 301, 187-203, 2003.

Bahnick, D., Sauer, C., Butterworth, B., Kuehl, D. A national study of mercury contamination of fish. *Chemosphere*, 29, 537-46, 1994.

Balluz, L.S., Philen, R.M., Sewell, C.M., Voorhees, R.E., Falter, K.H., Paschal, D. Mercury toxicity associated with a beauty lotion, New Mexico. *Intern. J. Epidemiol.*, 26, 1131-1132, 1997.

Barbosa, A.C., Jardim, W., Dorea, J.G., Fosberg, B., Souza, J. Hair mercury speciation as a function of gender, age, and body mass index in inhabitants of the Negro River basin, Amazon, Brazil. *Arch. Environ. Contam. Toxicol.*, 40, 439-44, 2001.

Barbosa, A.C., Silva, S.R., Dorea, J.G. Concentration of mercury in hair of indigenous mothers and infants from the Amazon basin. *Arch. Environ. Contam. Toxicol.*, 34, 100-105, 1998.

Barregård, L., Hultberg, B., Schutz, A., Salsten, G. Enzymuria in workers exposed to inorganic mercury. *Int. Arch. Occup. Environ. Health*, 61, 65-9, 1988.

Barregård, L., Sallsten, G., Jarholm, B. People with high mercury uptake from their own dental amalgam fillings. *Occup. Environ. Med.*, 52, 124-28, 1995.

Barregård, L., Sallsten, G., Schutz, A., Attewell, R., Skerfving, S., Jarvholm, B. Kinetics of mercury in blood and urine after brief occupational exposure. Arch. Environ. Health, 47, 176-84, 1992.

Barrios-Guerra, C.A. Mercury contamination in Chile: a chronicle of a problem foretold. *Rev. Environ. Contam. Toxicol.*, 183, 1-19, 2004.

Bellanger, T.M., Caesar, E.M., Trachtman, L. Blood mercury levels and fish consumption in Louisiana. *J. La State Med. Soc.*, 152, 64-73, 2000.

Bidone, E.D., Castilhos, Z.C., Cid de Souza, T.M., Lacerda, L.D. Fish contamination and human exposure to mercury in the Tapajos River Basin, Para State, Amazon, Brazil: a screening approach. *Bull. Environ. Contam. Toxicol.*, 59, 194-201, 1997.

Bird, H.R., Canino, I. The sociopsychiatry of espiritismo: findings of a study in psychiatric populations of Puerto Rican and other Hispanic children. *J. Am. Acad. Child Psychiatry*, 20, 725-40, 1981.

Birke, G., Johnels, A.G., Plantin, L.O., Sjostrand, B., Skerfving, S., Westermark, T. Studies on humans exposed to methyl mercury through fish consumption. *Arch. Environ. Health*, 25, 77-91, 1972.

Bloom, N.S. On the chemical form of mercury in edible fish and marine invertebrate tissue. *Can. J. Fish. Aquat. Sci.*, 49, 1010-1017, 1992.

Boischio, A.A., Cernichiari, E. Longitudinal hair mercury concentration in riverside mothers along the upper Madeira river (Brazil). *Environ. Res.*, 77, 79-83, 1998.

Boischio, A.A., Henshel, D.S. Linear regression models of methyl mercury exposure during prenatal and early postnatal life among riverside people along the upper Madeira river, Amazon. *Environ. Res.*, 83, 150-61, 2000.

Bruhn, C.G., Rodriguez, A.A., Barrios, C., Jaramillo, V.H., Becera, J., Gonzales, U., Gras, N.T., Reyes, O., Seremi-Salud. Determination of total mercury in scalp hair of pregnant and nursing women resident in fishing villages in the Eighth Region of Chile. *J. Trace Elem. Electrolytes Health Diss.*, 8, 79-86, 1994.

Burbacher, T., Shen, D., Clarkson, T. Mercury in Macaque infants following oral ingestion of methylmercury or IM injection of vaccines containing thimerosal. Presented in: "Mercury: Medical and Public Health Issues" Tampa, Florida, USA, 2004.

Burge, P., Evans, S. Mercury contamination in Arkansas game fish. A public health perspective. *J. Ark. Med. Soc.*, 90, 542-4, 1994.

Camara, V.M., Corey, G. Epidemiologic surveillance for substances banned from use in agriculture. *Bull. Pan. Am. Health. Organ.*, 28, 355-9, 1994.

Campbell, D., Gonzales, M., Sullivan, J.B. "Mercury" In: *Hazardous Materials Toxicology. Clinical Principles of Environmental Health.* JB Sullivan and G Rigger, eds. Baltimore, MD, Williams and Wilkins, 1992.

Carta, P., Flore, C., Alinovi, R., Ibba, A., Tocco, M.G., Aru, G., Carta, R., Girei, I., Mutti, A., Lucchini, R., Randaccio, F.S. Sub-clinical neurobehavioral abnormalities associated with low level of mercury exposure through fish consumption. *Neurotoxicology*, 24, 617-623, 2003.

Caurant, F., Navarro, M., Amiard, J-C. Mercury in pilot whales: possible limits to the detoxicifaction process. *Sci Tot. Env.*, 186, 95-104, 1996.

CDC. Centers for Disease Control. Thimerosal in vaccines: a joint statement of the American Academy of Pediatrics and the Public Health Service. *Morb. Mortal Wkly. Rep.*, 48, 563-5, 1999.

CDC. Centers for Disease Control. Summary of the joint statement on thimerosal in vaccines. American Academy of Family Physicians, American Academy of Pediatrics, Advisory Committee on Immunization Practices, Public Health Service. *Morb. Mortal Wkly. Rep.*, 49, 622-631, 2000.

CDC. Centers for Disease Control. Mercury poisoning associated with beauty cream – Texas, New Mexico, and California, 1995-1996. *Morb. Mortal Wkly. Rep.*, 45, 400, 1996.

Centers for Disease Control and Prevention. Second National Report on Human Exposure to Environmental Chemicals. NCEH Pub. No. 03-0022. January 2003. <222.cdc.gov/exposurereport/2nd/pdf/secondner.pdf>

Chan, H.M., A database for environmental contaminants in traditional foods in northern and Arctic Canada: development and applications. *Food Addit. Contam.*, 15, 127-34, 1998.

Chang, S.R., Siew, C., Gruninger, S.E. Factors affecting blood mercury concentrations in practicing dentists. *J. Dent. Res.*, 71, 66-74, 1992.

Cherian, M.G., Hursh, J.R., Clarkson, T.W., Allen, J. Radioactive mercury distribution in biological fluids and excretion in human subjects after inhalation of mercury vapor. *Arch. Environ. Health*, 33, 109-114, 1978.

Children's Amalgam Trial Study Group. The Children's Amalgam Trial: design and methods. *Control Clin. Trials*, 24, 795-814, 2003.

Cordier S., Grasmick C., Paquier-Passelaigue M., Mandereau L., Weber J., Jouan M. Mercury exposure in French Guiana: levels and determinants. *Arch. Environ. Health*, 53, 299-303, 1998.

Dallaire, F., Dewailly, E., Muckle, G., Ayotte, P. Time trends of persistent organic pollutants and heavy metals in umbilical cord blood of Inuit infants born in Nunavik (Quebec, Canada) between 1994 and 2001. Environ. Health Perspect., 111, 1660-4, 2003.

de Kom, J.F., van der Voet, G.B., de Wolff, F.A. Mercury exposure of Maroon workers in the small scale gold mining in Suriname. *Environ. Res.*, 77, 91-97, 1998.

Dietz, R., Riget, F., Johansen, P. Lead, cadmium, mercury, and selenium in Greenland marine animals. *Sci Tot. Env.*, 186, 67-93, 1996.

Dolbec, J., Mergler, D., Larribe, F., Roulet, M., Lebel, J., Lucotte, M. Sequential analysis of hair mercury levels in relation to fish diet of an Amazonian population, Brazil. *Sci. Tot. Env.*, 23, 87-97, 2001.

Dolbec, J., Mergler, D., Sousa Passos, C-J., Sousa de Morais, S., Lebel, J. Methylmercury exposure affects motor performance of a riverine population of the Tapajós river, Brazilian Amazon. *Int. Arch. Occup. Environ. Health*, 73, 195-203, 2000.

Dorea, J., Barbosa, A.C., Ferrari, I., de Souza, J.R. Mercury in hair and in fish consumed by Riparian women of the Rio Negro, Amazon, Brazil. *Int. J. Environ. Health Res.*, 13, 239-48, 2003.

Dos Santos, L.S., Muller, R.C., de Sarkis, J.E., Alves, C.N., Brabo, E.S., Santos, E.C., Bentes, M.H. Evaluation of total mercury concentrations in fish consumed in the municipality of Itaituba, Tapajos River Basin, Para, Brazil. *Sci Tot. Env.*, 261, 1-8, 2000.

Dumont, C., Girard, M., Bellavance, F., Noel, F. Mercury levels in the Cree population of James Bay, Quebec From 1988 to 1993/94. *CMAJ*, 158, 439-45, 1998.

Dunne, S.M., Gainsford, I.D., Wilson, N.H. Current materials and techniques for direct restorations in posterior teeth. Part 1. Silver amalgam. *Int. Dent. J.*, 47, 123-36, 1997.

Eisler, R. Mercury hazards from gold mining to humans, plants, and animals. *Rev. Environ. Contam. Toxicol.*, 181, 139-98, 2004.

Ekstrand, J., Bjorkman, L., Edlund, C., Sandborgh-Englund, G. Toxicological aspects on the release and systemic uptake of mercury from dental amalgam. *Eur. J. Oral. Sci.*, 106, 678-86, 1998.

Eley, B.M. The future of dental amalgam: a review of the literature. Part 4: Mercury exposure hazards and risk assessment. *Br. Dent. J.*, 182, 373-81, 1997a.

Eley B.M. The future of dental amalgam: a review of the literature. Part 6: Possible harmful effects of mercury from dental amalgam. *Br. Dent. J.*, 182, 455-9, 1997b.

Falter, R., Scholer, H.F. Determination of methyl-, ethyl-, phenyl and total mercury in Neckar River fish. *Chemosphere*, 29, 1333-38, 1994.

Forman, J., Moline, J., Cernichiari, E., Sayegh, S., Torres, J.C., Landrigan, M.M., Hudson, J., Adel, H.N., Landrigan, P.J. A cluster of pediatric metallic mercury exposure cases treated with meso-2,3-dimercaptosuccinic acid (DMSA). *Environ. Health Perspect.*, 108, 575-7, 1994.

Francis, P.C., Birge, W.J., Roberts, B.L., Black, J.A. Mercury content of human hair: a survey of dental personnel. *J. Toxicol. Environ. Health*, 10, 667-72, 1982.

Geffner, M.E., Sandler, A. Oral metallic mercury. A folk medicine remedy for gastroenteritis. *Clin. Pediatr. (Phila).*, 19, 435-37, 1980.

Gill, U.S., Schwartz, H.M., Bigras, L. Results of multiyear international interlaboratory comparison program for mercury in human hair. *Arch. Environ. Contam. Toxicol.*, 43, 466-72, 2002.

Gilmour, C.C., Riedel, G.S. A survey of size-specific mercury concentrations in game fish from Maryland fresh and estaurine waters. *Arch. Environ. Contam. Toxicol.*, 39, 53-59,

2000.

Gotelli, C.A., Astolfi, E., Cox, C., Cernichiari, E., Clarkson, T.W. Early biochemical effects of an organic mercury fungicide of infants: "dose makes the poison". *Science*, 227, 638-40, 1985.

Goyer, R.A., Clarkson, T.A. Toxic Effects of Metals pgs. 811 - 867. In: Casarett & Doull's Toxicology The Basic Science of Poisons 6th Edition. Klaassen C.D. (Ed). McGraw-Hill Pubs. New York, 2001.

Gunderson, E.L. FDA Total Diet Study. July 1986-April 1991. Dietary intakes of pesticides, selected elements, and other chemicals. *JAOAC Int.*, 78, 1353-1363, 1995.

Hacon, S., Yokoo, E., Valenta, J., Campos, R.C., da Silva, V.A., de Menezes, A.C., de Moraes, L.O., Ignotti, E. Exposure to mercury in pregnant women from Alta Floresta-Amazon basin, Brazil. *Environ. Res.*, 84, 204-10, 2000.

Hall, R.A., Zook, E.G., Meaburn, G.M. National Marine Fisheries Survey of Trace Elements in the Fishery Resource. NOAA Technical Report NMFS SSRF-721. Washington, D.C:US Department of Commerce. 1998.

Harada, M., Nakanishi, J., Yasoda, E., Pinheiro, M.C., Oikawa, T., De Assis Guimaraes, G., da Silva Cardoso, B., Kizaki, T., Ohno, H. Mercury pollution in the Tapajos River basin, Amazon: mercury level of head hair and health effects. *Environ. Int.*, 27, 285-90, 2001.

Haxton, J., Lindsay, D.G., Hislop, J.S., Salmon, L., Dixon, E.J., Evans, W.H., Reid, J.R., Hewitt, C.J., Jeffries, D.F. Duplicate diet study on fishing communities in the United Kingdom: mercury exposure in a "critical group". *Environ. Res.*, 18, 351-368, 1979.

Hempel, M., Chau, Y.K., Dutka, B.J., McInnis, R., Kwan, K.K., Liu, D. Toxicity of organomercury compounds: bioassay results as a basis for risk assessment. *Analyst*, 120, 721-4, 1995.

Henderson B. Dental amalgam: scientific consensus and CDA policy. *J. Can. Dent. Assoc.*, 61, 429-31, 1995.

Hightower, J.M., Moore, D. Mercury levels in high-end consumers of fish. *Environ. Health Perspect.*, 111, 604-608, 2003.

Hightower, J.M. " Mercury and clinical practice". Presented in: Mercury: Medical and Public Health Issues. April 28-30, 2004. Tampa, Florida, USA.

Ipolyi, I., Massanisso, P., Sposato, S., Fodor, P., Morabito, R. Concentration of levels of total and methylmercury in muscle samples collected along the coasts of Sardinia Island (Italy). *Analytica Chim. Acta*,505, 145-51, 2004.

Iyengar, V., Woittiez, J. Trace elements in human clinical specimens: evaluation of literature data to identify reference values. Clin Chem 1988; 34:474-81.

JECFA (Joint FAO/WHO Expert Committee on Food Additives). Sixty-first meeting. Rome. 10-19. June 2003. Summary and conclusions. Available from: URL:ftp://ftp/fao. org/es/esn/jecfa/jecfa61sc.pdf. Accessed June 8, 2004.

Jensen, J., Adare, K., Shearer, R. Canadian Arctic Contaminants Assessment Report. Department of Indian Affairs and Northern Development. 10 Wellington. Ottawa. Ontario K1A OH4. Canada 1997.

Jewett, S.C., Zhang, X., Naidu, A.S., Kelley, J.J., Dasher, D., Duffy, L.K. Comparison of mercury and methylmercury in northern pike and arctic grayling from western Alaska rivers. *Chemosphere*, 50, 383-92, 2003.

Johnsson, C., Sällsten, G., Schütz, A., Sjörs, A., Barregård, L. Hair mercury levels versus freshwater fish consumption in household members of Swedish angling societies. *Environ. Res.*, 96, 257-63, 2004.

Jones, D.W. Exposure or absorption and the crucial question of limits for mercury. *J. Can. Dent. Assoc.*, 65, 42-46, 1999.

Kales, S.N., Goldman, R.H. Mercury exposure: current concepts, controversies, and a clinic's

experience. *J. Occup. Environ. Med.*, 44, 143-54, 1999.

Kannan, K., Smith, R.G.Jr, Lee, R.F., Windon, H.L., Heitmuller, P.T., Macauley, J.M. Distribution of total mercury and methyl mercury in water, sediment, and fish from south Florida estuaries. *Arch. Environ. Contam. Toxicol.*, 34, 109-18, 1998.

Kershaw, T.G., Dhahir, P.H., Clarkson, T.W. The relationship between blood levels and dose of methylmercury in man. Arch. Environ. Health., 35, 28-36, 1980.

Kingman, A., Albertini, T., Brown, L.J. Mercury concentrations in urine and whole blood associated with amalgam exposure in a U S military population. *J. Dent. Res.*, 77, 461-71, 1980.

Kosatsky, T., Przybysz, R., Armstrong, B. Mercury exposure in Montrealers who eat St. Lawrence River sportfish. *Environ. Res.*, 84, 36-43, 2000.

Kosatsky, T., Przybysz, R., Shatenstein, B., Weber ,J-P., Armstrong, B. Fish consumption and contaminant exposure among Montreal-area sport fishers: pilot study. *Environ. Res.*, 80, S150-S158, 1999a.

Kosatsky, T., Przybysz, R., Shatenstein, B., Weber ,J-P., Armstrong, B. Contaminant exposure in Montrealers of Asian origin fishing the St. Lawrence River: Exploratory assessment. *Environ. Res.*, 80, S159-S165, 1999b.

Larsen, E.H., Andersen, N.L., Moller, A., Petersen, A., Mortensen, G.K., Petersen J. Monitoring the content and intake of trace elements from food in Denmark. *Food. Addit. Contam.*, 19, 33-46, 2002.

Lauwerys, R., Roels, H., Buchet, J.P., Bernard, A. Non-job related increased urinary excretion of mercury. *Int. Arch. Occup. Environ. Health*, 39, 33-6, 1977.

Lebel, J., Mergler, D., Branches, F., Lucotte, M., Amorim, M., Larribe, F., Dolbec, J. Neurotoxic effects of low-level methylmercury contamination in the Amazon basin. *Environ. Res.*, 79, 20-32, 1998.

Lecloux, A.J. Scientific activities of Euro Chlor in monitoring and assessing naturally and man-made organohalogens. *Chemosphere*, 52, 521-9, 2003.

Lefever, H.G. When the saints go riding in: Santeria in Cuba and the United States. *J. Sci. Study Religion*, 35, 318-30, 1996.

Litovitz, T.L., Smilkstein, M., Felberg, L., Klein-Felberg, L., Klein-Schwartz, W., Berlin, R., Morgan, J.L. 1996 annual report of the American Association of Poison Control Centers Toxic Exposure Surveillance System. *Am. J. Emerge. Med.*, 15, 447-500, 1997.

Lodenius, M., Malm, O. Mercury in the Amazon. Rev Environ Contam Toxicol 1998; 157:25-52.

MacIntosh D.L., Spengler J.D., Ozkaynak H., Tsai L., Ryan P.B. Dietary exposures to selected metals and pesticides. *Environ. Health. Perspect.*, 104, 202-09, 1996.

Mahaffey, K.R., Clickner, R.P., Bodurow, C.C. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. *Environ. Health. Perspect.*, 112, 562-570, 2004.

Mahaffey, K.R., Mergler D. Blood levels of total and organic mercury in residents of the upper St. Lawrence River basin, Quebec: association with age, gender, and fish consumption. *Environ. Res.*, 77, 104-114, 1998.

Marcovecchio, J.E., Gerpe, M.S., Bastida, R.O., Rodriguez, D.H., Moron, S.G. Environmental contamination and marine mammals in coastal waters from Argentina: an overview. *Sci. Tot. Env.*, 154, 141-51, 1994.

Mason, H.J., Hindell, P., Williams, N.R. Biological monitoring and exposure to mercury. *Occup. Med. (Lond.)*, 51, 2-11, 2001.

McDowell, M.A., Dillon, C.F., Osterloh, J., Bolger, P.M., Pellizzari, E., Fernando, R., Montes de Oca, R., Schoeber, S. E., Sinks, T., Jones, R. L., Mahaffey, K. R. Hair mercury levels in US children and women of childbearing age. Reference range data from NHANES 1999-2000. *Environ. Health Perspect.*, 112, 1165-71, 2004.

McKinney, P.E. Elemental mercury in the appendix: an unusual complication of Mexican-American folk remedy. *J. Toxicol. Clin. Toxicol.*, 37, 103-7, 1999.

Midthun, K. Thimerosal as a preservative in vaccines: An FDA perspective. Presented 2004 in "Mercury: Medical and Public Health Issues" Tampa, Florida. April 25-28, 2004.

Mol, J.H., Ramlal, J.S., Lietar, C., Verloo, M. Mercury contamination in freshwater, estuarine, and marine fishes in relation to small-scale gold mining in Suriname, South America. *Environ. Res.*, 82, 183-97, 2001.

Morgan, J.N., Berry, M.R.Jr., Graves, R.L. Effects of commonly used cooking practices on total mercury concentrations in fish and their impact on exposure assessments. *J. Expo. Anal. Environ. Epidemiol.*, 7, 119-133, 1997.

Morrissette, J., Takser, L., St.Amour, G., Smargiassi, A., Lafond, J., Mergler, D. Temporal variation of blood and hair mercury levels in pregnancy in relation to fish consumption history in a population living along the St. Lawrence River. *Environ. Res.*, 95, 363-74, 2004.

Muckle, G., Ayotte, P., Dewailly, E.E., Jacobson, S.W., Jacobson, J.L. Prenatal exposure of the northern Quebec Inuit infants to environmental contaminants. *Environ. Health Perspect.*, 109, 1291-9, 2001.

Nakagawa, R., Yunita, Y., Hiromoto, M. Total mercury intake from fish and shellfish by Japanese people. *Chemosphere*, 35, 2909-2913, 1997.

National Academy of Sciences. National Research Council. Committee on Toxicology of Methylmercury. *Toxicology of Methylmercury*. Washington DC: National Academy Press. 2000.

National Academy of Sciences. Institute of Medicine. Immunization Safety Review Committee. *Immunization Safety Review. Thimerosal-Containing Vaccines and Neurodevelopmental Disorders*. Stratton, K., Gable, A., and McCormick, M.C. Eds. Washington DC: National Academy Press. 2004.

National Institute for Occupational Safety and Health and Health (NIOSH). A Recommended Standard for Occupational Exposure to Inorganic Mercury. Washington, D.C. 1977

Niencheski, L.F., Windom, H.L., Baraj, B., Wells, D., Smith, R. Mercury in fish from Patos and Mirim Lagoons, Southern Brazil. *Mar. Pollut. Bull.*, 42, 1403-6, 2001,

Nilson, S.A. Jr., Costa, M., Akagi, H., Total and methylmercury levels of a coastal human population and of fish from the Brazilian northeast. *Environ. Sci. Pollut. Res. Int.*, 8, 280-4, 2001.

Ortiz-Roque, C., Lopez-Rivera, Y. Mercury contamination in reproductive age women in a Caribbean island: Vieques. *J. Epidemiol. Community Health*, 58, 756-7, 2004.

Palheta, D., Taylor, A. Mercury in environmental and biological samples from a gold mining area in the Amazon region of Brazil. *Sci Tot. Env.*, 19, 63-9, 1995.

Passos, C.J., Mergler, D., Gaspar, E., Morais, S., Lucotte, M., Larribe, F., Davidson, R., de Grosbois, S. Eating tropical fruit reduces mercury exposure from fish consumption in the Brazilian Amazon. *Environ. Res.*, 93, 123-130, 2003.

Penedo de Pinho, A., Daves Guinaraes, J.R., Martins, A.S., Costa, P.A., Olavo, G., Valentin, J. Total mercury in muscle tissue of five shark species from Brazilian offshore waters: effects of feeding habit, sex, and length. *Environ. Res.*, 89, 250-58, 2002.

Peters-Haefeli, L., Michod, J., Aellig, A., Varone, J.J., Schelling, J.L., Peters, G. Urinary mercury excretion in professional users of an antiseptic soap containing 0,04% phenylmercury borate. *Schweiz. Med. Wochenschr.*, 106, 171-8, 1976.

Pichichero, M.E., Cernichiari, E., Lopreiato, J., Treanor, J. Mercury concentrations and metabolism in infants receiving vaccines containing thiomersal: a descriptive study. *Lancet*, 360, 1737-41, 2002.

Piikivi, L., Tolonen, U. EEG findings in chlor-alkali workers subjected to low long term exposure to mercury vapour. *Br. J. Ind. Med.*, 46, 370-5, 1989.

Rhainds, M., Levallois, P., Dewailly, E., Ayotte, P. Lead, mercury, and organchlorine compound levels in cord blood in Quebec, Canada. *Arch. Environ. Health*, 54, 40-47, 1999.

Rice, D.C., Schoeny, R., Mahaffey, K.R. Methods and rationale for derivation of a reference dose for methylmercury by U.S. EPA. *Risk Anal.*, 23, 107-15, 2003.

Risher, J.F., Murray, H.E., Prince, G.R. Organic mercury compounds: human exposure and its relevance to public health. *Toxicol. Ind. Health*, 18, 109-60, 2002.

Rothschild, R.F., Duffy, L.K. Methylmercury in the hair of subsistence food users in a rural Alaskan village. *Alaska Med.*, 44, 2-7, 2002.

Saint-Phard, D., Gonzalez, P.G., Sherman, P. Poster 88. Unsuspected mercury toxicity linked to neurologic symptoms: A case Series. *Arch. Phys. Med. Rehabil.*, 85, E25, 2004.

Sakamoto, M., Kubota, M., Liu, X.J., Murata, K., Nakai, K., Satoh, H. Maternal and mercury and –3 polyunsaturated fatty acids as a risk and benefit of fish consumption to fetus. *Env. Sci Technol.*, 38, 3860-63, 2004.

Santos, E.C., de Jesus, I.M., Camara Vde, M., Brabo, E., Loureiro, E.C., Mascarenhas, A., Weirich, J., Luiz, R.R., Cleary, D. Mercury exposure in Munduruku Indians from the community of Sai Cinza, State of para, Brazil. *Environ. Res.*, 90, 98-103, 2002.

Sanzo, J.M., Dorrosoro, M., Amiano, P., Amurrio, A., Aguinagalde, F.X., Azpiri, M.A. Estimation and validation of mercury intake associated with fish consumption in an EPIC cohort of Spain. *Public Health Nutr.*, 4, 981-988, 2001.

Schober, S.E., Sinks, T.H., Jones, R.L., Bolger, P.M., McDowell, M., Osterloh, J., Garrett, E.S., Canady, R.A., Dillon, C.F., Sun, Y., Joseph, C.B., Mahaffey, K.R. Blood mercury levels in US children and women of childbearing age, 1999-2000. *J. Am. Med. Assoc.*, 289, 1667-74, 2003.

Schultz, C.D., Crer, D., Pearson, J.E., Rivera, J.E., Hylin, J.W. Total and organic mercury in the Pacific blue marlin. *Bull. Environ. Contam. Toxicol.*, 15, 230-234, 1976.

Seidel, S., Kreutzer, R., Smith, D., McNeel, S., Gilliss, D. Assessment of commercial laboratories performing hair mineral analysis. *JAMA*, 285, 67-72, 2001.

Sherlock, J.C., Hislop, J.E., Newton, D., Topping, G., Whittle, K. Elevation of mercury in human blood from controlled chronic ingestion of methylmercury in fish. *Hum. Toxicol.*, 3, 117-31, 1984.

Sherlock, J.C., Lindsay, D.R., Hislop, J.E., Evans, W.H., Collier, T.R. Duplication diet study on mercury by fish consumers in the United Kingdom. *Arch. Environ. Health*, 37, 271-278, 1982.

Sin, K.W., Tsang, H.F. Large-scale mercury exposure due to a cream cosmetic: community-wide case series. *Hong Kong Med. J.*, 95, 329-34, 2003.

Sing, K.A., Hryhorczuk, D., Saffrio, G., Sinks, T., Paschal, D.C., Sorensen, J., Chen, E.H. Organic mercury levels among the Yanomama of the Brazilian Amazon Basin. *Ambio*, 32, 434-9, 2003.

Skerfving, S. Methylmercury exposure, mercury levels in blood and hair, and health status in Swedes consuming contaminated fish. *Toxicology*, 2, 3-23, 1974.

Smith, J.C., Allen, P.V., Turner, M.D., Most, B., Fisher, H.L., Hall, L.L. The kinetics of intravenously administered methyl mercury in man. *Toxicol. Appl. Pharmacol.*, 128, 251-56, 1994.

Smith, R.G., Vorwald, A.J., Patil, L.S., Mooney, T.F.Jr. Effects of exposure to mercury in the manufacture of chlorine. *Am. Ind. Hyg. Assoc. J.*, 31, 687-700, 1970.

Stajich, G.V., Lopez, G.P., Harry, S.W., Sexson, W.R. Iatrogenic exposure to mercury after hepatitis B vaccination in preterm infants. *J. Pediatr.*, 136, 678-81, 2000.

Stern, A.H., Gochfeld, M., Weisel, C., Burger, J. Mercury and methylmercury exposure in the New Jersey pregnant population. *Arch. Environ. Health*, 56, 4-10, 2001.

Stern, A.H., Smith, A.E. An assessment of the cord blood-maternal blood methylmercury

ratio: implications for risk assessment. *Environ. Health. Perspect.*, 111, 1465-70, 1970.
Storelli, M.M., Marcotrigiano, G.O. Fish for human consumption: risk of contamination by mercury. *Food Addit. Contam.*, 17, 1007-11, 2000.
Storelli, M.M., Stuffler, R.G., Marcotrigiano, G.O. Total and methylmercury residues in tuna-fish from the Mediterranean sea. *Food. Addit. Contam.*, 19, 715-20, 2002.
Suzuki, T., Miyama, T., Toyama, C. The chemical form and bodily distribution of mercury in marine fish. *Bull. Environ. Contam. Toxicol.*, 10, 347-55, 1973.
Swift, J.A. Morphology and histochemistry of human hair. *EXS*, 78, 149-75, 1997.
Tsugane, S., Kondo, H. The mercury content of hair of Japanese immigrants in various locations in South America. *Sci Tot. Env.*, 63, 69-76, 1987.
Urieta, I., Jalon, M., Eguilero, I. Food surveillance in the Basque Country (Spain). II. Estimation of the dietary intake of organochlorine pesticides, heavy metals, arsenic, aflatoxin M1, Iron, and zinc through the Total Diet Study 1990/91. *Food Addit. Contam.*, 13, 29-52, 1996.
US EPA. Task Force on Ritualistic Use of Mercury Report Mercury is used to attract luck, love, or money. It is also used to protect against evil. http://www.epa.gov/superfund/action/ community/mercury.pdf 2002.
US EPA. Fact Sheet:Proposed Rule to Reduce Toxic Air Pollutants Mercury Cell Chlor-Alkali Plants. http://www.epa.gov/ttn/oarpg/t3/fact_sheets/mccap_fs.pdf
US EPA. Background Report: AP-42 Section 5.5: Chlor-Alkali Industry. An emission factor relates the quantity of pollutants emitted to a unit of activity. URL:http://www.epa.gov/ttn/chief/ap42/ch08/bgdocs/b08s11.pdf 1992.
US EPA. Mercury Study Report to Congress. Volume IV. An Assessment of Exposure to Mercury in the United States. URL: http://www.epa.gov/oar/mercury.html 1997.
US FDA. Center for Drug Evaluation and Research. Mercury in Drug and Biologic Products Retrieved May 2004 from: http://www.fda.gov/cder/fdama/mercury300.htm
US Occupational Safety and Health Administration. Job Health Hazards Series. Mercury. OSHA Report 2234. 1975.
Van Oostdam, J., Gilman, A., Dewailly, E., Usher, P., Wheatley, B., Kuhnlein, H., Neve, S., Walker, J., Trace, B., Feeley, M., Jerome, V., Kwavnick, B. Human health implications of environmental contaminants in Arctic Canada: a review. *Sci. Tot. Env.*, 230, 1-82, 1999.
Veiga, M.M. Protocols for environmental and health assessment of mercury released by Artisanal and small -scale gold miners (ASM). Global Mercury Project. UNIDO Project EG/GLO/01/G#$: Removal of Barriers to Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies. Vienna: United Nations Industrial Development Organization. 2004.
Veiga, M.M. UNIDO/UBC/CETEM. Introducing new technologies for abatement of global mercury pollution in Latin America. Ed. UNIDO/UBC/CETEM. Rio de Janeiro. 94 p. ISBN: 85-7227-100-7, 1997.
Wagemann, R., Innes, S., Richard, P.R. Overview and regional and temporal differences of heavy metals in Arctic whales and ringed seals in the Canadian Arctic. *Sci. Tot. Env.*, 186, 41-66, 1996.
Wagemann, R., Trebacz, E., Boila, G., Lockhart, W.L. Methylmercury and total mercury in tissues of arctic marine mammals. *Sci. Tot. Env.*, 218, 19-31, 1998.
Wangberg, I., Edner, H., Ferrara, R., Lanzillotta, E., Munthe, J., Sommar, J., Sjoholm, M., Svanberg, S., Weibring, P. Atmospheric mercury near a chlor-alkali plant in Sweden. *Sci. Tot. Env.*, 304, 29-41, 2003.
Weiner, J.A., Nylander, M. The relationship between mercury concentration in human organs and different predictor variables. *Sci. Tot. Env.*, 138, 101-15, 1993.

Weldon, M.M., Smolinski, M.S., Maroufi, A., Hasty, B.W., Gilliss, D.L., Boulanger, L.L., Ballus, L.S., Dutton, R.J. Mercury poisoning associated with a Mexican beauty cream. *West J. Med.*, 173, 15-18, 2000.

Wharton, M., "Thimerosal and Vaccines: CDC Perspectives". Mercury: Medical and Public Health Issues. Tampa, Florida. April 25-28, 2004.

WHO - World Health Organization. *Environmental Health Criteria 101. Methylmercury.* Geneva. World Health Organization. 1990.

WHO - World Health Organization. *Environmental Health Criteria 118. Inorganic Mercury.* Geneva: World Health Organization. 1991.

Ysart, G., Miller, P., Crosdale, M., Crews, H., Robb, P., Baxter, M., de L'Argy, C., Harrison, N. 1997 UK Total Diet Study - Dietary exposures to aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel selenium, tin, and zinc. *Food Addit. Contam.*, 17, 775-786, 2000.

Zaidi, M., Angulo, M., Sifuentes-Osornio, J. Disinfection and sterilization practices in Mexico. *J Hosp. Infect.*, 31, 25-32, 1995.

Zayas, L.H., Ozuah, O. Mercury use in Espiritismo: a survey of botanicas. *Am. J. Public Health*, 86, 111-112, 1996.

Zeitz, P., Orr, M.F., Kaye, W.E. Public health consequences of mercury spills: Hazardous Substances Emergency Events Surveillance System, 1993-1998. *Environ. Health Perspect.* 110, 129-32, 2002.