4 Current mercury exposures and risk evaluations for humans

4.1 Overview

259. As mentioned earlier, the general population is primarily exposed to methylmercury through the diet (especially fish) and to elemental mercury vapours due to dental amalgams. Depending on local mercury pollution load, substantial additional contributions to the intake of total mercury can occur through air and water. Also, personal use of skin-lightening creams and soaps, mercury use for religious, cultural and ritualistic purposes, the presence of mercury in some traditional medicines (such as certain Traditional Asian remedies) and mercury in the home or working environment can result in substantial elevations of human mercury exposure. For example, elevated air levels in homes have resulted from mercury spills from some old gas meters and other types of spills. Also, elevated mercury levels in the working environment have been reported for example in chlor-alkali plants, mercury mines, thermometer factories, refineries and dental clinics (WHO/IPCS, 1991), as well as in mining and manufacturing of gold extracted with mercury. Additional exposures result from the use of Thimerosal or Thiomersal (ethylmercury thiosalicylate) as a preservative in some vaccines and other pharmaceuticals. The national submissions to UNEP for this assessment indicate that the relative impacts of mercury from local pollution, occupational exposure, certain cultural and ritualistic practices, and some traditional medicines may today vary considerably between countries and regions in the world, and are significant in some regions.

260. Examples of data on total mercury and methylmercury exposures primarily from fish diets, but also other sources in different parts of the world, including Sweden, Finland, the USA, the Arctic, Japan, China, Indonesia, Papua New Guinea, Thailand, Republic of Korea, Philippines, the Amazonas and French Guyana are provided in section 4.4. For example, in a study of a representative group of about 1700 women in the USA (aged 16-49 years) for years 1999-2000, about 8 percent of the women had mercury concentrations in blood and hair exceeding the levels corresponding to the US EPA's reference dose (an estimate of a safe dose, see section 4.2.1). As shown in the chapter, data indicate exposures are generally higher in Greenland, Japan and some other areas compared to the USA. Other examples of human exposures exist and have been submitted for use in this report. Unfortunately, it has not been possible to present all submitted examples here.

261. In some of these countries and areas, local and regional mercury depositions have affected the mercury contamination levels over the years and countermeasures have been taken during the last decades to reduce national emissions. Mercury emissions are, however, distributed over long distances in the atmosphere and oceans. This means that even countries with minimal mercury emissions, and other areas situated remotely from dense human activity, may be adversely affected. For example, high mercury exposures have been observed in the Arctic, far distances from any significant sources of releases.

262. Data on mercury concentrations in fish have been submitted from a number of nations and international organisations. Additionally, many investigations of mercury levels in fish are reported in the literature. Submitted data, giving examples of mercury concentrations in fish from various locations in the world, are summarised for illustrative purposes in table 4.5. The mercury concentrations in various fish species are generally from about 0.05 to 1.4 mg/kg depending on factors such as pH and redox potential of the water, and species, age and size of the fish. Since mercury biomagnifies in the aquatic food web, fish higher on the food chain (or of higher trophic level) tend to have higher levels of mercury. Hence, large predatory fish, such as king mackeral, pike, shark, swordfish, walleye, barracuda, large tuna (as opposed to the small tuna usually used for canned tuna), scabbard and marlin, as well as seals and toothed whales, contain the highest concentrations. The available data indicate that mercury is present all over the globe (especially in fish) in concentrations that adversely affect human beings and wildlife. These levels have led to consumption advisories in a number of countries (for fish, and some-

times marine mammals), warning people, especially sensitive subgroups (such as pregnant women and young children), to limit or avoid consumption of certain types of fish from various waterbodies. Moderate consumption of fish (with low mercury levels) is not likely to result in exposures of concern. However, people who consume higher amounts of contaminated fish or marine mammals may be highly exposed to mercury and are therefore at risk.

4.2 Evaluations of exposure levels causing risks

4.2.1 Methylmercury

263. As mentioned, intake of methylmercury in fish and other aquatic foods is considered the most serious general impact on humans. Based on risk assessments and other societal considerations, several countries and international organisations have established risk evaluation tools such as levels of daily or weekly methylmercury or mercury intakes considered safe (Reference Dose and Provisional Tolerable Weekly Intake), limits/guidelines for maximum concentrations in fish and fish consumption advisories.

264. Table 4.1 gives an overview of examples of maximum allowed or recommended levels of mercury in fish in various countries (based on submissions to UNEP, unless otherwise noted). Also, examples of tolerable intake levels of mercury or methylmercury are mentioned.

Table 4.1 Examples of maximum allowed or recommended levels of mercury (Hg) in fish in various countries and by WHO/FAO (based on submissions to UNEP, unless otherwise noted).

Country/ Organization	Fish type	Maximum allowed/recommend levels in fish *1	Type of measure	Tolerable intake levels *1
Australia	Fish known to contain high levels of mercury, such as swordfish, southern bluefin tuna, barramundi, ling, orange roughy, rays, shark All other species of fish and crustaceans and molluscs	1.0 mg Hg/kg 0.5 mg Hg/kg	The Australian Food Standards Code	Tolerable Weekly Intake: 2.8 μg Hg/kg body weight per week for pregnant women.
Canada	All fish except shark, swordfish or fresh or frozen tuna (expressed as total mercury in the edible portion of fish) Maximum allowable limit for those who consume large amounts of fish, such as Aboriginal people	0.5 ppm total Hg 0.2 ppm total Hg	Guidelines/ Tolerances of Various Chemical Contaminants in Canada	Provisional Tolerable Daily Intake: 0.47 μg Hg/kg body weight per day for most of the population and 0.2 μg Hg/kg body weight per day for women of childbearing age and young children
China	Freshwater fish	0.30 mg/kg	Sanitation standards for food	
Croatia	*Fresh fish* Predatory fish (tuna, swordfish, molluscs, crustaceans) All other species of fish *Canned fish (tin package)* Predatory fish (tuna, swordfish, molluscs, crustaceans) All other species of fish	1.0 mg Hg/kg 0.8 mg methylHg/kg 0.5 mg Hg/kg 0.4 mg methylHg/kg 1.5 mg Hg/kg 1.0 mg methylHg/kg 0.8 mg Hg/kg 0.5 mg methylHg/kg	Rules on quantities of pesticides, toxins, mycotoxins, metals and histamines and similar substances that can be found in the food	
European Community *2	Fishery products, with the exception of those listed below. Anglerfish, atlantic catfish, bass, blue ling, bonito, eel, halibut, little tuna, marlin, pike, plain bonito, portuguese dogfish, rays, redfish, sail fish, scabbard fish, shark (all species), snake mackerel, sturgeon, swordfish and tuna.	0.5 mg Hg/kg wet weight 1 mg Hg/kg wet weight	Various Commission decisions, regulations and Directives	

Country/ Organization	Fish type	Maximum allowed/recommend levels in fish *1	Type of measure	Tolerable intake levels *1
Georgia	Fish (freshwater) and fishery products Fish (Black Sea) Caviar	0.3 mg Hg/kg 0.5 mg Hg/kg 0.2 mg Hg/kg	Georgian Food Quality Standards 2001	
India	Fish	0.5 ppm total Hg	Tolerance Guidelines	
Japan	Fish	0.4 ppm total Hg/kg 0.3 ppm methylHg (as a reference)	Food Sanitation Law - Provisional regulatory standard for fish and shellfish	Provisional Tolerable Weekly Intake: 0.17 mg methylHg (0.4 µg/kg body weight per day) (Nakagawa *et al.*, 1997).
Korea, Republic of	Fish	0.5 mg Hg/kg	Food Act 2000	
Mauritius	Fish	1 ppm Hg	Food Act 2000	
Philippines	Fish (except for predatory) Predatory fish (shark, tuna, swordfish)	0.5 mg methylHg /kg 1 mg methylHg/kg	Codex Alimentarius	
Slovak Republic	Freshwater non-predatory fish and products thereof Freshwater predatory fish Marine non-predatory fish and products thereof Marine predatory fish	0.1 mg total Hg/kg 0.5 mg total Hg/kg 0.5 mg total Hg/kg 1.0 mg total Hg/kg	Slovak Food Code	
Thailand	Seafood Other food	0.5 µg Hg/g 0.02 µg Hg/g	Food Containing Contaminant Standard	
United Kingdom	Fish	0.3 mg Hg/kg (wet flesh)	European Statutory Standard	
United States	Fish, shellfish and other aquatic animals (FDA) States, tribes and territories are responsible for issuing fish consumption advise for locally-caught fish; Trigger level for many state health departments:	1 ppm methylHg 0.5 ppm methylHg	FDA action level Local trigger level	US EPA reference dose: 0.1 µg methylHg/kg body weight per day
WHO/FAO	All fish except predatory fish Predatory fish (such as shark, swordfish, tuna, pike and others)	0.5 mg methylHg/kg 1 mg methylHg/kg	FAO/WHO Codex Alimentarius guideline level	JECFA provisional tolerable weekly intake: 3.3 µg methylHg/kg body weight per week.

Note: 1 Units as used in references. "mg/kg" equals "µg/g" and ppm (parts per million). It is assumed here that fish limit values not mentioned as "wet weight" or "wet flesh" are most likely also based on wet weight, as this is normally the case for analysis on fish for consumers.

2 The European Commission has recently (February 2002) revised the previous maximum limit values for mercury in a small number of specific fish species for consumption (Commission Regulation No 221/2002 of 6 February 2002). These changes are not reflected in the table.

Recent risk evaluation process in USA

265. Three comprehensive risk evaluations on methylmercury were recently completed in the USA by the Environmental Protection Agency (EPA), the Agency for Toxics Substances and Disease Registry (ATSDR) and the National Research Council (NRC). All three are summarized here with greater detail given for the EPA evaluation, as it is a very recent comprehensive evaluation and presents one example of a scientific approach to estimate a safe exposure level.

266. The earlier-mentioned NRC evaluation was initiated by the EPA upon the request of the US Congress, and it is has been part of a major effort by the EPA to review the available toxicological findings on methylmercury as a basis for a re-evaluation of the EPA reference dose (RfD). The RfD is generally defined as an "estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." The methylmercury RfD is used by the EPA to evaluate the potential for adverse health effects from exposure to methylmercury for humans as well as establishing guidance for fish consumption advisories (NRC, 2000; NIEHS, 1998; US EPA, 1997).

267. The RfD is a daily intake of methylmercury for which "exposures" (intake) at or below the RfD are expected to be safe. The risks following exposures above the RfD are uncertain, but risk increases as exposure to methylmercury increases above the RfD (US EPA, 1997). In 1995, an RfD was set by the EPA on the basis of neurological effects observed on children exposed prenatally (in the mothers womb) to methylmercury in the poisoning incidence in Iraq (epidemiological data transformed by calculations from observed mercury concentrations in maternal hair to daily intakes – divided by a safety factor of 10 due to biological variability and insufficient data on reproductive effects on adults). The NRC evaluation committee concluded in 2000 that the value of the US EPA's RfD for methylmercury, 0.1 micrograms of methylmercury per kilogram body weight per day, "is a scientifically justifiable level for the protection of public health". However, the committee recommended that the above-mentioned results from the Faroe Islands study should be used for the US EPA's determination of a new RfD instead of the Iraq study (NRC, 2000). The NRC recommended an uncertainty factor (UF) of not less than 10 to account for variability in human kinetics (i.e., pharmacokinetics) and sensitivity of the fetus' brain to methylmercury. The NRC review and the studies were again reviewed by an external expert panel, and then the US EPA evaluation was presented in 2001 (US EPA, 2001b), as part of a water quality criterion.

268. The US EPA evaluation includes a thorough analysis of the relevant studies, especially those conducted on children from the Faroe Islands and the Seychelles islands. Since the results from these two studies disagree, the merits and weaknesses of the studies were discussed, as well as possible reasons for the conflicting results. Both studies were considered being of high quality, and no serious flaws could be detected. In this situation, the US EPA decided to use data from the Faroe Islands study (which showed a negative effect on neurological development related to methylmercury exposures) as the starting point to derive the RfD. Similar results from the smaller New Zealand study as well as some later cross-sectional studies from other parts of the world, contributed to this conclusion.

269. The current RfD was derived from a benchmark dose (BMD) divided by an uncertainty factor of 10. The BMD analysis used was based on the lower 95 percent confidence limit for a 5 percent effect level (above background) applying a linear model to dose-response data based on cord blood mercury. The cord blood data were converted to maternal intakes. Several of the neuropsychological tests used, and also an integrated analysis gave similar results with respect to benchmark doses. Most of these endpoints yielded RfDs of about 0.1 µg/kg body weight per day (comm-24-gov). Overall, the EPA RfD was primarily based on a number of neurological endpoints and the weight of evidence from the Faroe Islands and the New Zealand study, plus an integrated analysis of those two studies plus the Seychelles study. Other models for the benchmark analyses are possible (Budtz-Jørgensen *et al.*, 2000) and resulted in lower benchmark dose limits, but the linear model was considered the most appropriate one (Pirrone *et al.*, 2001). The US EPA chose an uncertainty factor of 10 accounting for pharmacokinetic inter-individual variability, gaps of knowledge on possible long term effects, and uncertainty concerning the relationships between cord and maternal blood mercury concentration, and as mentioned, the US EPA's current RfD was set at 0.1 µg/kg body weight per day (US EPA, 2001b, and Pirrone *et al.*, 2001). A daily average methylmercury intake of 0.1 µg/kg body weight per day by an adult woman is estimated to result in hair mercury concentrations of about 1 µg/g, cord blood levels of about 5 to 6 µg/l and blood mercury concentrations of about 4-5 µg/l. However, there are limitations, uncertainties and variability in these estimates. These estimates were derived from data and methods presented in US ATSDR, 1999; NRC, 2000; US EPA, 2001b and US EPA, 1997.

270. Based on an average daily intake of 17.5 gram of fish, the US EPA also calculated a Tissue Residue Criterion of 0.3 mg methylmercury per kg of fish (0.3 mg/kg). This limit is weighted on all fish and shellfish consumed. For higher intakes, a lower limit would be needed. Additionally, US EPA calculated a set of recommendations for fish consumption limits based on the above mentioned risk assessment, see table 4.2 (US EPA, 2001b).

271. Consumption limits have been calculated as the number of allowable fish meals per month based on the ranges of methylmercury in the consumed fish tissue. For example, when methylmercury

levels in fish tissue are 0.4 mg/kg, then two 0.23 kg meals per month can safely be consumed. The following assumptions were used to calculate the consumption limits:

- Consumer adult body weight of 72 kg (less meals recommended if lower body weight);
- Average fish meal size of 0.23 kg;
- Time-averaging period of 1 month (30.44 d);
- EPA's reference dose for methylmercury (0.1 μg/kg body weight per day) from EPA's Water Quality Criterion for the Protection of Human Health: Methylmercury (US EPA, 2001b).

Table 4.2 US EPA's monthly fish consumption limits for methylmercury (US EPA, 2001b).

Max. number of fish meals/month	Fish tissue concentrations (ppm = mg/kg, wet weight)
16	> 0.03–0.06
12	> 0.06–0.08
8	> 0.08–0.12
4	> 0.12–0.24
3	> 0.24–0.32
2	> 0.32–0.48
1	> 0.48–0.97
0.5	> 0.97–1.9
None (<0.5)*	> 1.9

* None = No consumption recommended.

> means "above" (example "> 0.06–0.08" means: "above 0.06 to 0.08")

272. Using an alternative approach, the US ATSDR developed its current Minimal Risk Level (MRL) of 0.3 μg/kg body weight per day for methylmercury using the Seychelles Child Development Data (US ATSDR, 1999). The MRL is an estimate of the level of human exposure to a chemical that does not entail appreciable risk of adverse non-cancer health effects. They are intended for use by the public health officials as screening tools to determine when further evaluation of potential human exposure at hazardous waste sites is warranted.

Europe

273. Guidelines for maximum mercury concentrations in fish and consumption advice vary somewhat among the European countries. In 2001, a group of European scientists evaluated the risks from mercury exposure in Europe and presented their view in this regard in their "Position Paper on Mercury" (Pirrone *et al.*, 2001). Regarding methylmercury, they recommended that the US EPA reference dose should apply in Europe also, stating that:

> "We share the view of the recent evaluations by the US EPA and NRC. No new information has emerged that would change the risk assessment. Moreover, the considerations made for the USA will be valid also for the European population. We therefore consider the US EPA RfD of 0.1 μg per kg body weight (and day) to be appropriate for Europe. It should be noted that it is mainly relevant for fertile women, and that it includes an uncertainty factor.
>
> The reference dose will be exceeded if a substantial amount of fish, contaminated with mercury, is ingested. As an example, if the weekly intake is about 100 g (one typical fish meal per week) of fish with > 0.4 mg/kg, the RfD will be exceeded. This suggests that fish mercury levels should be kept below this limit.
>
> Fish is, however, a valuable part of the diet, in adults as well as in children, and a source of e.g. protein, vitamin E, selenium, and omega 3 fatty acids. At high consumption of fish with low levels of mercury, like in the Seychelles Islands, the advantages and disadvantages may counterbalance each other. Because of the beneficial effects of fish consumption, the long-term aim is not to replace fish in the diet by other foods, but to reduce the methylmercury concentrations in fish. If this

is not possible, dietary restrictions with respect to fish with high levels of methylmercury should be advised for pregnant women."

274. An additional overview of some toxicological reference values (and briefs on their background) from a number of countries, and covering a few more mercury compounds, is given in the document "Compilation of toxicological and environmental data on chemicals – mercury and its derivates" (INERIS, 2000) submitted by France (can be viewed from UNEP's GMA home page, link: http://www.chem.unep.ch/mercury/gov-sub/Sub49govatt18.pdf).

275. The current EU limits for mercury in fish can be tightened for health reasons in individual member countries. Thus, some EU member states have lower limits than required by the directive. Because of high mercury concentrations in fish, certain lakes and rivers are closed to sports fishing, e.g., in Sweden. In addition, EU member states such as Denmark, Finland, Sweden and the United Kingdom, address specific advisories to sensitive populations. These can include women who are pregnant, plan to become pregnant, or who breast-feed, and children, in regard to avoiding or limiting the intake of fish species where the EU limit of 1 mg/kg applies (Finnish National Authority for Foodstuff, 2002)

UN Organizations

276. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a provisional tolerable weekly intake (PTWI) of 200 µg (equivalent to 3.3 µg/kg body weight) for methylmercury in 1978, which was confirmed in 1988. In 1999, the Committee evaluated the Faroe Islands and Seychelles studies available at that time, as well as new neurodevelopmental toxicity studies in animals, and concluded that the studies did not provide consistent evidence of neurodevelopmental effects in children of mothers whose intake of methylmercury yielded hair burdens of 20 µg/g or less. The Committee could not evaluate the risks for the complex and subtle neurological end-points used in these studies that would be associated with lower intakes. In the absence of any clear indication of a consistent risk in these recent studies, the Committee recommended that methylmercury be re-evaluated when the 96-month evaluation of the Seychelles cohort and other relevant data that may become available can be considered. The Committee thus did not revise the PTWI of 3.3 µg/kg body weight.

4.2.2 Elemental mercury vapour and inorganic mercury compounds

277. For mercury vapour, studies of occupationally exposed humans have shown slight adverse effects on the central nervous system and kidneys at long-term air levels of 25-30 µg/m^3 or equivalent urinary mercury levels of 30-35 µg/g creatinine. Based on the LOAEL for effect on the central nervous system, the US EPA determined a reference concentration (RfC) for mercury vapour of 0.3 µg/m^3 for the general population (US EPA, 1997). The RfC took into account a conversion from occupational exposure to continuous exposure for the general population, lack of data on reproductive effects, the use of a LOAEL instead of a NOAEL, and susceptible subgroups. The US ATSDR established a minimum risk level (MRL) of 0.2 µg/m^3, also based on the occupational data. [2] Using the ATSDR document as the source document, and complementing the information with further studies on adverse effects observed among workers exposed to mercury vapour, and on studies on the relationship between concentrations of mercury in urine/blood of exposed workers and in the breathing zone air, IPCS identified 0.2 µg/m^3 as a guidance value for long-term inhalation exposure of the general public to metallic mercury vapour (WHO/IPCS, 2002).

278. In the European Position Paper on mercury (Pirrone *et al.*, 2001) it was concluded that – under European conditions – human exposure to elemental mercury in ambient air is generally negligible. As mentioned elsewhere, the case may be different in regions with higher direct air pollution loads. The following risk evaluation was presented:

[2] The USA, in their comments to this report (comm-24-gov), has stated the following as a remark to the risk evaluation presented by Pirrone *et al.* (2001): "The United States Government has used the best available data to determine safe exposure levels. These estimates are significantly above the 0.05 µg/m^3 value discussed in this paragraph (eds.: Quote of Pirrone *et al.*'s risk evaluation), but are nonetheless believed to be protective of health."

"For mercury vapour, studies of occupationally exposed humans have shown slight adverse effects on the central nervous system and kidneys, and probably also on the thyroid, at long-term air levels of 25-30 μg/m³ or equivalent urinary mercury levels of 30-35 μg/g creatinine. The US EPA determined a reference concentration (RfC) for mercury vapour of 0.3 μg/m³ for the general population (US EPA, 1997). Recent studies suggested that the limit for adverse effects (LOAEL) in occupationally exposed subjects may be lower than indicated above. There is no universal agreement on which uncertainty factors to use. In ongoing work on a EU position paper on arsenic, cadmium, and nickel, factors of 5-10 were used for similar conversion from occupational exposure to continuous exposure, factors of 5-10 for the use of a LOAEL, and a factor of 10 for variation of susceptibility. The total factor was 500. A similar procedure would result in a limit value for elemental mercury of 0.05 μg/m³. We propose the use of 25 μg/m³ as starting point, a factor of 10 for continuous exposure of the general population during a whole life-time, and uncertainty factors of 5 for the use of a LOAEL and 10 for individual susceptibility. The proposed limit value will then be 0.05 μg/m³, as an annual average. This air level is rarely exceeded in ambient air in Europe, however. A typical daily absorbed dose would be 0.6-0.8 μg of mercury for adults. Exposure to elemental mercury from dental amalgam in most cases represents a much higher daily uptake than this level would give rise to (WHO/IPCS, 1991)."

279. Studies on exposed humans do not provide sufficient information to derive acceptable intakes for inorganic mercury compounds; therefore, based on No adverse effects and lowest adverse effects in medium- and long-term animal experiments, ATSDR and IPCS derived a guidance value of 0.2 μg/kg body weight per day for inorganic mercury compounds (US ATSDR, 1999; WHO/IPCS, 2002).

4.3 Routes of mercury exposure – a general overview

280. As mentioned above, the general population is primarily exposed to methylmercury through the diet (especially fish) and to elemental mercury vapours due to dental amalgams.

281. Human exposure to the three major forms of mercury present in the environment is summarised in table 4.3 in section 4.3.1. Although the choice of values given is somewhat arbitrary, this table nevertheless provides a perspective on the relative magnitude of the contributions from various media. Humans may be exposed to additional quantities of mercury occupationally and in heavily polluted areas, and to additional forms of mercury, e.g. to aryl and alkoxyaryl compounds, which are still used as fungicides in some countries. The following paragraphs present general contributions to human mercury exposure in a bit more detail, as reviewed by Pirrone *et al.* (2001), except for the text on occupational exposure.

Elemental mercury vapour from ambient air and dental fillings

282. Regarding vapour of metallic mercury, dental fillings, and to a lesser extent, the ambient air, represent the two major sources of human exposure for the general population. From the atmosphere the daily amount absorbed as a result of respiratory exposure into the bloodstream in adults is about 32 ng mercury in rural areas and about 160 ng mercury in urban areas, assuming rural concentrations of 2 ng/m³ and urban concentrations of 10 ng/m³ (absorption rate 80 percent).

283. Local contributions from airborne mercury may vary greatly depending on emissions from local sources. For example, the Indian submission (sub71govatt1) reports observed elevated mercury exposure in an area influenced heavily by emissions from thermal power plants. Another example is the submission of the Slovak Republic reporting ambient air concentration in urban areas in Slovakia in the range of 1.7 – 20 ng/m³ (geometric mean 4.57 ng/m³) and in industrial areas in the range of 1.5–40 ng/m³ (geometric mean 5.28 ng/m³), with the highest levels in areas with metallurgic industry and coal combustion (Hladiková *et al.*, 2001, as presented in sub10gov). Elevated air levels may also occur downwind from some types of emissions sources such as chlor-alkali plants.

284. Release of mercury from amalgam fillings has been reviewed by Clarkson et al. (1988). It was concluded that amalgam surfaces release mercury vapour into the mouth, and this is the predominant

source of human exposure to elemental mercury in the general population. Depending upon the number of amalgam fillings, the estimated average daily absorption of mercury vapour from dental fillings vary between 3 and 17 µg mercury (WHO/IPCS, 1991; Clarkson et al., 1988; Skare and Engqvist, 1994). In rare cases the blood mercury levels due to dental amalgam may be as high as 20 µg/l (Barregard et al. 1995, as quoted by Pirrone et al., 2001). Effects of exposure from dental amalgam has been widely discussed and reviewed (US Public Health Service, 1993, as quoted by Pirrone et al., 2001; and others). However, the Working Group for this Global Mercury Assessment, in line with its mandate, focused on environmental exposures to mercury and their adverse effects on health, and did not review or assess the potential effects of exposures to elemental mercury vapour from dental amalgams or the possible conversion to other mercury forms in the body. Moreover, the Working Group did not reach any conclusions about whether or not dental amalgams cause adverse effects.

Indoor non-occupational air exposure

285. Very little data are available on non-occupational indoor human exposure due to mercury vapour. However, fatalities and severe poisonings have resulted from heating metallic mercury and mercury-containing objects in the home. Also, incubators used to house premature infants have been found to contain mercury vapour at levels approaching occupational threshold limit values; the source was mercury droplets from broken mercury thermostats. In addition, significant exposures can occur due to use of metallic mercury in religious, ethnic, or ritualistic practices. Exposures can occur during the practice and afterwards from contaminated indoor air. A few of the activities reported that result in human mercury exposures include sprinkling elemental mercury in homes or cars, mixing mercury in bath water or perfume or placing mercury in candles (US ATSDR, 1999).

286. Indoor air mercury levels can also become elevated due to leaks from central-heating thermostats and by the use of vacuum cleaners after thermometer breakage and other spills. Another source of exposure to mercury vapor has been the release of mercury from paint containing mercury compounds used to prolong shelf-life of interior latex paint, in which levels of 0.3-1.5 µg Hg/m^3 (Beusterien *et al.*, 1991) have been reported. However, as explained in other sections of this report, the use of mercury in paints has decreased substantially in many nations of the world, therefore this source of exposure may be less common today than it was 10-30 years ago.

Drinking water

287. Mercury in drinking water is usually in the range of 0.5-100 nanograms of mercury per litre of water (ng Hg/l), the average value being about 25 ng Hg/l. The forms of mercury in drinking water are not well studied, but Hg(II) is probably the predominant species present as complexes and chelates with ligands. The resulting intake from drinking water is about 50 ng mercury per day, mainly as Hg(II); only a small fraction is absorbed. There are reports of methylmercury in drinking water under some conditions. It is, however, considered to be quite unusual (USA; comm-24-gov).

Intake from foods

288. Concentrations of mercury in most foodstuffs are often below the detection limit (usually 20 ng Hg per gram fresh weight) (US EPA, 1997). Fish and marine mammals are the dominant sources, mainly in the form of methylmercury compounds (70-90 percent or more of the total). The normal mercury concentrations in edible tissues of various species of fish cover a wide range, generally from 0.05 to 1.400 mg/kg fresh wet weight depending on factors such as pH and redox potential of the water, species, age and size of the fish (see sections 4.4 and 4.5). Large predatory fish, such as king mackeral, pike, shark, swordfish, walleye, barracuda, scabbard and marlin, as well as seals and toothed whales, contain the highest average concentrations. While large tuna typically have levels of mercury that are similar to other large predatory fish, data indicate that the levels usually seen in canned tuna are substantially lower. This results from the fact that the tuna currently used for canned tuna are those of smaller size.

289. The intake of mercury depends not only on the level of mercury in fish, but also the amount consumed. Thus, many governments have provided dietary advice to consumers to limit consumption

where levels are elevated. Fish consumption advisories typically take into account suspected concentrations, amount of fish - or canned fish - consumed and patterns of consumption.

290. Intake of fish and fish products, averaged over months or weeks, results in an average daily absorption of methylmercury variously estimated (in the 1970's) to be between 2 and 4.7 µg mercury (WHO/IPCS, 1976). The absorption of inorganic mercury from foodstuffs is difficult to estimate because levels of total mercury are close to the limit of detection in many food items and the chemical species and ligand binding of mercury have not usually been identified. The average daily intake of total dietary mercury has been measured over a number of years for various age groups. The intake of total dietary mercury (µg/day) measured during a market basket survey (1984-1986) of the Food and Drug Administration (FDA) in the USA (WHO/IPCS, 1990), according to age group was: 0.31 µg (6-11 months); 0.9 µg (2 years) and 2-3 µg in adults. In Belgium, two surveys estimated the total mercury intake from all foodstuffs to vary between 6.5 µg and 13 µg mercury (Fouasuin and Fondu, 1978; Buchet *et al.*, 1983).

Occupational exposure

291. Mercury in the working environment can lead to elevated exposures. As described in chapter 3 on human toxicology, a significant amount of the knowledge on the toxic effects of mercury and its compounds has been attained through the investigation of occupational exposures. Depending on the types of occupational activity and extent of implemented protective measures, the severity of effects may range from the subtlest disturbances to serious damages and death. Occupational exposures can happen in virtually all working environments where mercury is produced, used in processes or incorporated in products. Occupational exposure has been reported from – among others – chlor-alkali plants, mercury mines, mercury-based gold extraction, processing and sales, thermometer factories, dental clinics with poor mercury handling practices and production of mercury-based chemicals (US ATSDR, 1999).

292. In many countries a general improvement of protection against occupational exposure has taken place during the last decades by introduction of a range of working environment improvements including more closed manufacturing systems, better ventilation, safe handling procedures, personal protection equipment and through substitution of mercury-based technologies. This does, however, not seem to be a universal development, and many workers may still be exposed to mercury levels causing risks.

293. An example of the potential for improvements through implementation of such improvements and substitutions is that reported by Zavaris (1994) concerning mercury concentrations in employees exposed to mercury in specific industries: chlor-alkali, electric light bulbs, batteries and control instruments. Initially about 17 percent of the workers exceeded the legal limits for mercury in urine. After subsequent improvement in the working environment, and in some cases substitution of the mercury-based technology, in the industries involved, more than 98 percent of urinary levels had returned to the range of normal levels (abstracts of occupational exposure and industrial protection/substitution studies submitted by Brazil, sub66govatt6).

294. A UNIDO study has reported on the effects of mercury intoxication in the gold-mining area of Diwalwal, dominated by Mount Diwata (also known as Mt. Diwalwal), on the island of Mindanao - one of the major islands of the Philippines. At the time of the study, more than 70 percent (73 of 102) of the occupationally exposed population suffered from chronic mercury intoxication. Among the occupational sub-group of amalgam smelter workers the percentage was even higher – 85.4 percent. Of the non-occupationally exposed population in the area of Mt. Diwata and downstream, approximately one-third (55 of 163) showed signs of chronic mercury intoxication, including such classical symptoms as memory problems, restlessness, loss of weight, fatigue, tremor, sensory disturbances, and bluish discolouration of the gums (Böse-O'Reilly *et al.*, 2000).

Other exposures

295. Exposure to organic mercury, inorganic mercury or elemental mercury might occur through the use of mercury-containing skin-lightning creams, some traditional medicines, ritualistic uses, and cer-

tain pharmaceuticals (US ATSDR, 1999; Pelclova *et al.*, 2002). For example, thimerosal (ethylmercury thiosalicylate), also known as thiomersal, is used for preservation of some types of vaccines and immunoglobulins in parts of the world. Significant exposures can also occur from use of some Traditional Chinese Medicines or Traditional Asian Medicines (Ernst and Coon 2001; Koh and Woo, 2000; Garvey *et al.*, 2001).

4.3.1 Estimated Average Exposures

296. The WHO (1990) estimated the daily intake of each form of mercury as shown in table 4.3. For details on the methodology and assumptions used, see original reference. This table presents average estimated intakes for the different routes of exposure. However, exposures vary considerably across populations. For example, people who consume greater amounts of mercury-contaminated fish will obviously have greater exposures to methylmercury than those shown in the table.

Table 4.3 Estimated average daily intake and retention in the body (retention given in brackets) of different mercury forms in a scenario relevant for the general population not occupationally exposed to mercury, values in µg/day (WHO/IPCS, 1991; for more details, consult reference).

Exposure	Elemental Hg vapour	Inorganic Hg compounds	Methylmercury
Air	0.03 (0.024)*	0.002 (0.001)	0.008 (0.0069)
Dental amalgams	3.8-21 (3-17)	0	0
Food			
- fish	0	0.60 (0.042)	2.4 (2.3)**
- non-fish	0	3.6 (0.25)	0
Drinking water	0	0.050 (0.0035)	0
Total	3.9-21 (3.1-17)	4.3 (0.3)	2.41 (2.31)

Note: The data in brackets represent retained part of mercury input in the body of an adult.

* If the concentration is assumed to be 15 ng/m^3 in an urban area, the figure would be 0.3 (0.24) µg/day.

** Assumes 100 g of fish per week with the mercury concentration of 0.2 mg/kg.

297. When relating the intakes of the different mercury species in table 4.3, it should be remembered that their toxic impacts varies. [3] Therefore, it is not contradictory that the methylmercury intakes are lower than other mercury intakes, but still generally constitute the major adverse impact on humans from mercury compounds.

4.3.2 General aspects of dietary mercury intake

298. Daily intakes and retention of mercury from food is difficult to estimate accurately. In most food stuff mercury concentration is below 20 µg/kg. Mercury is known to bioconcentrate in aquatic organisms and it is biomagnified in aquatic food webs. For example, the concentration of mercury in small fish at low food web level (such as anchovies) is below 0.085 mg/kg, while in swordfish, shark and tuna values above 1.2 mg/kg are frequently reported (WHO/IPCS, 1991). In Scandinavian predatory fresh-water fish (perch and pike) average levels are about 0.5 mg/kg.

299. The use of fishmeal as the feed for poultry and other animals used for human consumption may result in increased levels of mercury. In Germany, the poultry contains 0.03 - 0.04 mg/kg. Cattle are able to demethylate mercury in the rumen, and therefore, beef meat and milk contain very low concentrations of mercury.

300. One of the major problems to accurately estimate daily intakes of various mercury forms from diet is that national survey programmes mainly report total mercury concentrations and the percentage of mercury as methylmercury is not known. Total mercury daily intakes reported in various countries

[3] Some conversion of elemental mercury takes place in the body, and therefore the species humans are exposed to may not necessarily be the species actually inflicting the specific toxicological mechanisms.