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:

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[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/m^3 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/m^3 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/m^3. We propose the use of 25 µg/m^3 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/m^3, 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/m^3 and urban concentrations of 10 ng/m^3 (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/m^3 (geometric mean 4.57 ng/m^3) and in industrial areas in the range of 1.5–40 ng/m^3 (geometric mean 5.28 ng/m^3), 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 mg/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

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[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.

are given in table 4.4. In some national surveys the percentage of mercury originating from fish is provided. It is assumed that in this foodstuff (fish) the percentage of methylmercury is from 60 to 90 percent. Therefore fish and fish products represent the major source of methylmercury. It may be concluded that in those areas where fish consumption represent a considerable part of diet, exposures could be considerably higher than the value of the US EPA RfD.

Table 4.4 Selected estimates of the typical daily intake of mercury from dietary sources in a selection of countries (as presented by Pirrone et al.*, 2001).*

Country	**Intake (mg/day)**	**References**
Belgium	All food: 13 of which 2.9 is from fish All foodstuff: 6.5	Fouassin and Fondu, 1978 Buchet *et al*., 1983
Poland	5.08 (age group 1-6 years) 5.43 (age group 6-18 years) 15.8 in adults From fish: 7% of total dietary intake	Szprengier-Juszkiewicz, 1988 Nabrzyski and Gajewska, 1984
Germany	0.8 from fish 0.2 from food (except fish and vegetables)	LAI, 1996
Croatia	From fish: 27.7 (total Hg) 20.8 (MeHg form)	Buzina *et al*., 1995
Spain	4-8 (60-90 % from seafood) in Valencia only 27% is from the seafood 18 of which about 10 is from fish (Basque country)	Moreiras *et al*., 1996 Urieta *et al*., 1996
Sweden	1.8 (market-basket)	Becker and Kumpulainen, 1991
United Kingdom	2	MAFF, 1994
Finland	2	Kumpulainen and Tahvonen, 1989
The Netherlands	0.7	Van Dokkum *et al*., 1989
Czech Rep.	0.7	Ruprich, 1995
Brazil	315 – 448 (Amazon, Medeira river)	Boishio and Henshel, 2000
Japan	10 6.9 –11.0 24 (18 as MeHg)	Tsuda *et al*., 1995 Ikarashi *et al*., 1996 Nakagawa *et al*., 1997

301. Pirrone *et al.* (2001) give the following conclusion regarding the general exposure pattern in Europe:

> “Mercury vapour is a risk of decreasing importance in Europe, as mercury-containing thermometers and other instruments are being phased-out, and the emissions from the chlor-alkali industry have decreased. In addition, only one mercury mine remains in operation in Europe today. New developments in dental technology have resulted in filling materials that can substitute amalgam for many purposes.
>
> The methylmercury risk will depend on the dietary habits and local sources of contaminated fish and seafood. The substantial exposures documented in the Faroe Islands, Greenland and other northern populations are mainly due to ingestion of marine mammals. The extent of this problem within Europe is therefore limited. However, a study from the island of Madeira showed that the consumption of local black scabbard resulted in average methylmercury exposures that were even higher than on the Faroe Islands. Similarly, evidence on mercury in seafood from the Tyrrhenian Sea have shown concentration levels which overlap with those present in pilot whale meat. Thus, excess exposures occur in Europe and may reach or even exceed levels observed in populations in which adverse effects on brain development have been documented. “

302. This conclusion may possibly apply to large parts of the western world.

4.4 Exposure through diets of fish and marine mammals

303. In the following sections, examples of data on methylmercury exposure from fish diets in different parts of the world are presented: Sweden, Finland, USA, the Arctic, Japan, China, Indonesia, Papua New Guinea, Thailand, Republic of Korea, the Amazonas and French Guyana. In some of these countries or areas mercury depositions have affected mercury contamination levels over years, and countermeasures have been set in during the last decades to reduce national emissions. Mercury emissions are, however, distributed over long distances in the atmosphere and by the oceans. This means that even countries with minimal local and national mercury emissions, and other areas situated remotely from dense human activity, may very well be similarly affected. For example, high mercury exposures have been observed in the Arctic, far distances from any significant sources of releases.

304. 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 in this chapter. The overview illustrates that mercury is present all over the globe in concentrations that may affect human beings and wildlife.

4.4.1 Exposure from fish diet in Sweden and Finland

305. According to von Rein and Hylander (2000), fish has traditionally been an important part of the diet in Sweden thanks to a long coastline and many lakes and rivers. Today, because of mercury contents in the fish, detailed recommendations for the consumption are given for fresh water fish such as pike, perch, pike-perch, burbot and eel. Women of childbearing age are recommended not to eat these fish from Swedish lakes at all, and the rest of the population should not eat them more than once a week. Based on comprehensive data sets, it has been estimated that in about 50 percent of the approximately 100,000 Swedish lakes, pike (1 kg size) contain mercury levels above the international WHO/FAO limit of 0.5 mg mercury/kg wet weight, and in 10 percent of the lakes pike contains over 1 mg/kg wet weight (Lindquist *et al.*, 1991). It has been calculated that the mercury deposition in Sweden must decrease by 80 percent from the level of the late 1980's in order to reduce the mercury content in Swedish fish to below 0.5 mg mercury/kg wet weight. The emissions to air from point sources in Sweden itself have decreased to about 1 metric ton/year from peak values in the 1960's of around 30 metric tons/year, and releases to water have been reduced similarly (Naturvårdsverket, 1991). Most of the present mercury deposition in Sweden originates from long-range atmospheric transport from other countries (Håkansson and Andersson, 1990; Iverfeldt *et al.*, 1995). This means that in order to meet the 80 percent reduction goal, emissions from Europe and other parts of the Northern hemisphere must also be reduced further. There are indications of recent reductions in deposition, and during the last few decades a general decrease of about 20 percent has been observed in mercury concentrations in fish in Sweden (Johansson *et al.*, 2001).

306. Also in Finland, the accumulation of mercury in fish has been studied during several decades (Louekari *et al.*, 1994). In the late 1960's about 10-15 percent of the lakes and coastal waters in Finland were affected by elevated mercury concentrations mainly caused by direct aqueous releases from pulp and paper industry and (related) mercury-based chlor-alkali production. Average concentrations of mercury in northern pike in these freshwaters and brackish coastal waters averaged as much as 1.52 mg/kg wet weight at that time. Since the abandonment of the use of mercury compounds for slimicides in paper production in Finland in 1968 and decreasing demand for chlorine in the same industry, releases of mercury have been reduced significantly. In 1990 average concentrations in pike in these waters had decreased to 0.60 mg mercury/kg wet weight (concentrations in pikes in freshwaters were generally higher than in brackish waters). Louekari *et al.* (1994) combined these findings with dietary surveys and calculated estimated daily intakes of mercury in different consumer segments, and the relative influence of pike/fish consumption. In 1967/68, mercury intakes of the farmer segment known to be most depending on locally caught fish were estimated at 22 μg mercury/day in the areas with elevated mercury contamination. Similar intakes in 1990 were estimated at 15 μg mercury/day. For office employees, who consume less locally caught fish, corresponding intakes were 13 and 8 μg mercury/day.

307. The mercury concentration limit of 0.5 mg/kg in fish, recommended by WHO/FAO, is exceeded for one-kilo pike (*Esox lucius*) in 85 per cent of the lakes in southern and central Finland (22,000 lakes), (Lindquist *et al.*, 1991; Verta 1990; all in Pirrone *et al.*, 2001).

4.4.2 Exposure from fish diet in the USA

308. In the mid-1990's the US EPA estimated from comprehensive national dietary surveys that up to 5 percent of women in the child bearing age (ages 15-44 years) in the USA consumed 100 grams of fish and shellfish per day or more. WHO recommends "special considerations" regarding mercury exposure for persons eating more than 100 g/day. Furthermore, the US EPA calculated from the same dietary surveys combined with average total mercury concentrations in the species of fish consumed, that 7 percent of US women in the child-bearing age may exceed the exposure of the US EPA RfD (see section 4.2.1). A recent study (by the US Centers for Disease Control and Prevention) of mercury concentrations measured in blood and hair in a representative group of women aged 16-49 in the USA (about 1700 women) confirmed these calculations, as approximately 8 percent of the women had hair and blood mercury levels exceeding the levels corresponding to the US EPA RfD (CDC, 2001; Schober *et al.*, 2003). The CDC also collected hair and blood samples for year 2002, but these results are not yet available. Moreover, the CDC plans to continue the blood measurements in future years, but the hair samples are not planned after year 2002.

309. The US EPA noted that the calculated results reflected the average choice of fish species, and that "consumption of fish with mercury levels higher than average may pose a significant source of methylmercury exposure to consumers of such fish" (elevated mercury concentrations have been measured in fish in quite a number of freshwater bodies in the USA). The US EPA concluded in their risk characterisation that "most USA consumers need not be concerned about their exposure to mercury", but the exposure of "those who regularly and frequently consume large amounts of fish" (especially species with high mercury concentrations), may be of concern (US EPA, 1997).

310. In the USA, fish advisories (consumption recommendations) have been issued for mercury in one or more freshwater bodies in 41 states, and 13 states have issued statewide mercury fish advisories. Mercury is the most frequent basis for fish advisories in the USA, representing 79 percent of all advisories (as of December 2000; US EPA, 2001a). The US EPA has presented a set of general recommendations for fish consumption. For example, fish with mercury concentrations ranging from 0.48 -0.97 mg methylmercury/kg wet weight should be eaten no more than once a month and with 0.97 - 1.9 mg/kg wet weight only every second month, whereas fish containing more than 1.9 mg/kg wet weight should not be eaten at all (US EPA, 2001a); see table 4.2 in section 4.2.1 above.

311. Fish sold in commerce in the USA are under the jurisdiction of the Food and Drug Administration (FDA), which issues action levels for concentration of mercury in fish and shellfish. The current FDA action level (as per 1998) is 1 ppm (1 mg/kg) total mercury based on a consideration of health impacts. As illustrated in table 4.5 in section 4.5, US freshwater fish can have mercury levels which exceed the FDA action limit of 1 ppm. The levels in some marine species such as shark, swordfish, and king mackeral are also typically this high. The concentration of methylmercury in commercially important marine species is on average close to ten times lower than the FDA action level in the USA. Mercury levels in marine fish have been monitored by the National Marine Fisheries Service for at least 20 years. The data in marine fish have shown mercury levels over this time to be relatively constant in various species. Comparable trends data for freshwater fish do not exist, although there are data for coastal and estuarine sites (US EPA, 1997).

312. See also the description of Canadian experiences related to mercury in aquatic ecosystems, including a map showing national fish mercury concentrations, in section 5.3.

4.4.3 Exposure from marine diet in the Arctic

313. The comprehensive AMAP (1998) assessment report on arctic pollution issues describes the high exposures of the Arctic population. AMAP and other Arctic Council activities relevant to mercury

cover the whole of the Arctic region, and mercury is a priority substance for assessment and abatement initiatives for the Council. Here, examples of mercury exposure in Greenland are given.

314. As for much of the population in the region, the diet in Greenland is to a high degree composed of marine mammals and also fish. The traditional Greenlandic diet is also a very important part of the Greenlandic culture and identity.

315. The concentration and distribution of mercury in humans in Greenland have been thoroughly studied in the last 15 years. Surveys have been performed in adults, pregnant women and newborn babies in most parts of Greenland including both hunting districts and more densely populated areas. In all regions studied, the determining factors for mercury exposure were the daily intake of meat from marine mammals. At a regional level, the blood mercury concentrations were directly proportional to the registered number of seals caught (and consumed), indicating that mercury concentration in meat is probably similar in all regions of Greenland (Hansen, 1990). In adults, whole blood concentrations of mercury are lowest in the Southwest and increasing towards the North where the intake of marine mammals is higher – see figure 4.1.

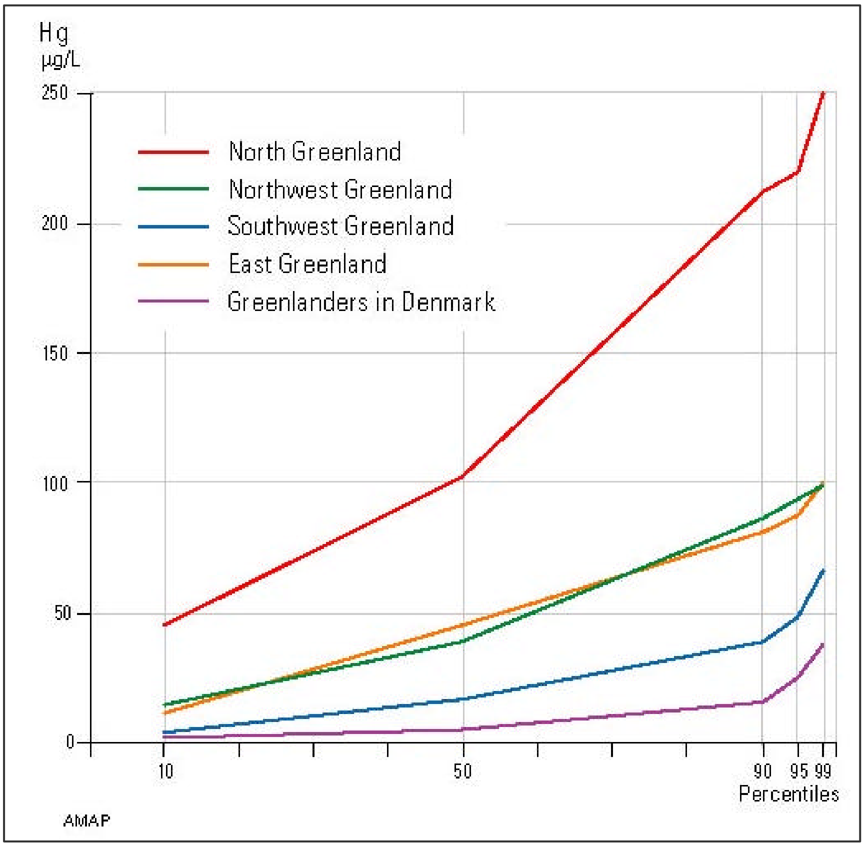


Figure 4.1 Distribution (in percentiles) of whole blood mercury concentrations in four regions in Greenland and in Greenlanders living in Denmark (AMAP, 1998, based on 1988 measurements). Original figure presented courtesy of AMAP, Norway.

316. In North Greenland, 16 percent of the adult population studied had blood mercury concentrations exceeding 200 µg/l, which is the level regarded by WHO as the minimum toxic blood concentration in non-pregnant adults (AMAP, 1998). More than 80 percent of the population in North Greenland exceeded 50 µg/l blood (Hansen and Pedersen, 1986), which almost corresponds to the benchmark dose level from the US NRC report (2000). Blood levels of 200 µg/l are approximately the level expected to occur following a daily average intake of about 4 µg methylmercury per kg body weight per day. Likewise, a daily intake of about 1 µg methylmercury per kg body weight per day is expected to result in blood mercury levels of about 50 µg/l and hair mercury levels of about 10 µg/g (US EPA, 1997; US ATSDR, 1999).

317. In a small set of 20 paired samples of maternal and umbilical cord blood taken under the AMAP programme, the mean concentrations were 24.2 and 53.8 µg/l, respectively. This level is very close to the NRC (2000) benchmark dose level (58 µg/l) based on the NRC evaluation of the Faroe Islands studies (see section 3.2.1).

318. As of 1997, no disease or symptoms had been registered which could be unequivocally related to environmental contaminant exposure in Greenland (AMAP, 1998). However, it should be noted that this can generally not be done for environmental contaminants because of its complexity, except in cases of extreme acute or sub-acute exposure. Furthermore, at that time measurements of more subtle neurological and reproductive effects had not yet taken place in Greenland. A recent study suggested exposure-related neurobehavioral deficits in Inuit children in Qaanaaq, Greenland, but the study was too small to provide solid statistical significance of the associations (Weihe *et al.*, 2002).

319. The traditional marine diet on Greenland and in parts of Arctic Canada has very positive nutritional qualities and is not readily replaced with other foods. Dietary advice from the Canadian Government states that the positive health benefits of a traditional northern marine diet outweigh the known risks associated with consumption of these foods. However, it is clear that the risks associated with this diet increase with increasing levels of methylmercury contamination. It is further important to note that, beyond the physical benefits associated with the traditional diet, it also plays an important role in the social and cultural life of indigenous communities in the North.

320. As mentioned above, the investigation of mercury exposure and effects on the Faroe Islands on the border of the Arctic area has been extensive, and subtle neurological effects have been shown on children at low prenatal exposure levels, see description in section 3.2.1 above.

321. The Arctic Council and the substantial coverage of mercury in its monitoring and assessment programme (AMAP) and its current action plan (ACAP) are described in section 9.5.1.

4.4.4 Examples from Asia

China, Japan and Indonesia

322. Feng *et al.* (1998) investigated total mercury and methylmercury concentrations in scalp hair of 243 male persons in three areas of the Tokushima Prefecture, Japan as well as in 64 males of the Chinese city Harbin and 55 males in the Indonesian city Medan (all subjects were randomly chosen males aged 40-49 years). They found the highest concentrations in subjects living in a seaside area reported to be without local direct anthropogenic contamination. Total mercury concentrations here ranged from 1.7-24 µg/g hair (mean 6.2 µg/g, 78 subjects), thus close to and exceeding the adverse effect benchmark level of about 10 µg/g maternal hair derived from the Faroe Islands studies (see section 3.2). The mean concentration for all three investigated areas in Japan was only slightly lower: 4.6 µg/g hair (243 subjects).

323. In Japan, where the diet is relatively high in fish and shellfish, methylmercury constituted large parts of the total mercury measured, and there was a high correlation between concentrations of methylmercury and total mercury, underlining that a marine diet was the major contributor to mercury exposure. Feng *et al.* (1998) quote the Japan General Affairs Department for 1996 dietary surveys estimating average national consumption of fish and shellfish at 107 g/day per person, being the third highest consumption rates among 23 countries investigated.

324. In the industrial cities of Harbin, China, and Medan, Indonesia, Feng *et al.* (1998) found lower mean total mercury concentrations (means 1.7 µg/g and 3.1 µg/g hair respectively). In both of these places methylmercury concentrations were lower – even for subjects with high total mercury concentrations - and correlation between methylmercury and total mercury concentrations was low, indicating that these subjects were mainly exposed to elemental or inorganic mercury from other sources.

Papua New Guinea

325. Feng *et al.* (1998) quotes Suzuki (1991) for mercury hair concentration levels found in residents of three villages in Papua New Guinea not influenced by local direct anthropogenic contamination. The highest concentrations were found in the seaside village Dorogi with means at 4.1 and 4.4 µg/g hair for males and females respectively, while concentrations were slightly lower in a riverside village 6 kilometres from the coast and lowest in a village 25 kilometres from the coast.

Thailand

326. For Thailand, the national submission (sub53gov) quotes Menasveta (1993) for an average national fish consumption rate of 61 g/day per person for Thai people (with average weight 60 kg). There is no study on hazards from methylmercury exposure of the Thai population.

Philippines

327. The average estimated national fish consumption rate is 75 g/person per day, and the average person weighs 60 kg. Also, the exposures described in the study by UNIDO (described in section 4.3 above) on mercury intoxication on the island of Mindanao (a gold-mining area) are probably partially due to exposures through the diet, especially for the non-occupationally burdened part of the population downstream from Mt. Divalwal, where approximately a third (55 of 163) are intoxicated (Global Mercury Assessment Working Group - Philippines delegation, 2002).

Republic of Korea

328. According to the national submission from the Republic of Korea, the supply of fish amounted to between 74 and 94 g fish/day per person in this country in the years 1996-1999 (Republic of Korea submission, sub76govatt2).

4.4.5 Exposure from fish diet in the Amazonas and French Guyana, South America

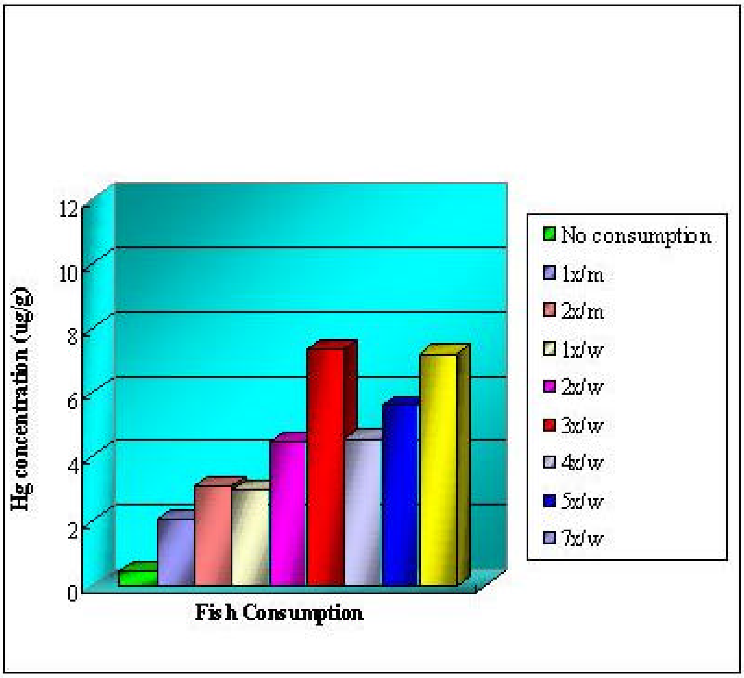
329. Several studies in the Amazonas have reported elevated exposures to methylmercury and total mercury in fish dependent populations in and around areas affected by mercury-based gold extraction.

330. Some studies in the Amazonas have shown adverse effects from mercury exposure on humans. For example, in the Tapajós river community of Brazil, cognitive deficits have recently been reported in 7-year children who were exposed, in uterus, to mercury levels corresponding to maternal hair mercury levels below 10 µg/g hair (Malm *et al.*, 1999, as quoted the in Brazilian submission sub66govatt2A). Quite a number of studies have investigated exposures and toxic impacts from mercury in individual areas affected by gold mining activities in the Amazonas. The Ministry of Health, Brazil, reports to be in the process of reviewing the available exposure data from the Amazon area with fish consumption and mercury concentration in fish as focal points (sub66govatt2A). The Ministry has also submitted a list of a large number of references relevant to the impacts of mercury in the Amazon (sub66govatt2B).

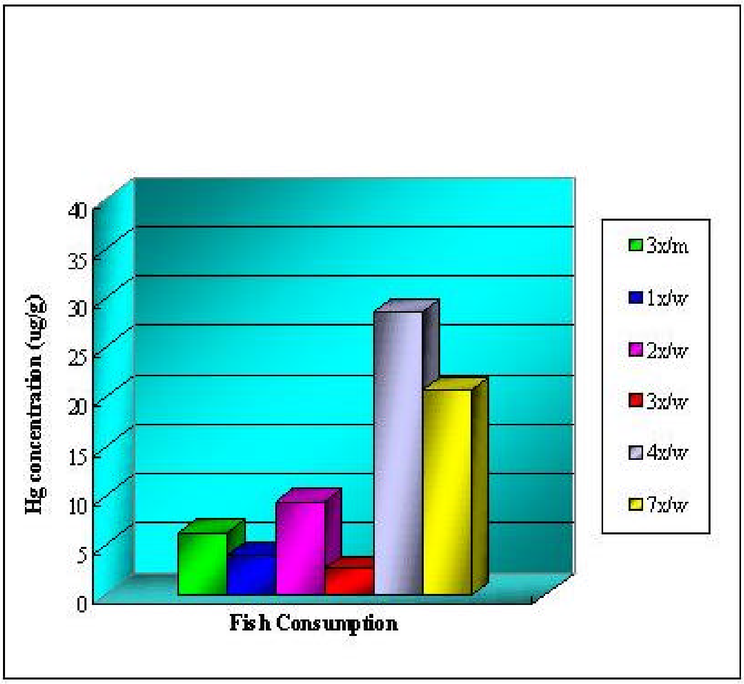
331. Akagi and Naganuma (2000) used separate measurements of methylmercury and total mercury to distinguish between exposures through an aquatic diet and direct exposures of elemental mercury from gold extraction activities. They found methylmercury concentrations exceeding the adverse effects level for adults of 50 µg/g in hair in 3.2 percent of the 559 inhabitants surveyed, with the highest individual level being 132 µg/g. These values are substantially higher than the adverse effect benchmark level of 10 µg/g maternal hair derived from the Faroe Islands studies (see section 3.2.1).

332. Vasconcellos *et al.* (1998) determined total mercury concentrations in scalp hair in 13 of the 17 tribes of Indians inhabiting the Xingu Park in the Brazilian Amazon. In six of the investigated groups methylmercury concentrations in hair were also measured. Geometrical means for total mercury concentrations varied among the tribes in the range of 3.2-21 µg/g hair, but most group means were between 10 and 20 µg/g. In the tribes where methylmercury was also measured, methylmercury comprised nearly all of the mercury found in the hair samples. In the same study, three groups of inhabitants in the Brazilian State of Amapá were also investigated. Total mercury in hair versus numbers of fish

meals per week are shown in figure 4.2 - first for a region not affected directly by gold extraction (figure 4.2 a) and then for another region which is affected by gold extraction (figure 4.2 b).



a) Total mercury concentrations in hair versus fish consumption – region of Serra do Navio, State of Amapá, Brazil (not directly affected by gold extraction)



b) Total mercury concentrations in hair versus fish consumption – region of Vila Nova, State of Amapá, Brazil (directly affected by gold extraction)

Figure 4.2 Total mercury concentrations in hair vs fish consumption in two regions of the State of Amapá, Brazil (from Vasconcellos et al.*, 1998, submitted by Brazil, sub68govatt1)*

333. Some researchers have considered if gold extraction alone could explain the observed mercury contamination levels in the Amazonas area. Other mercury sources mentioned are volcanic contributions and increased mobilisation due to deforestation and other sources of soil erosion (based on USA, comm-24-gov, 2002).

French Guyana

334. A study undertaken by Fréry *et al.* (1999) among the Wayana people in the higher area of the Maroni River, French Guyana, whose diet is based mainly on fish, confirmed mercury exposure due to consumption of river fish contaminated by mercury from gold extraction activities. Of 242 fish samples analysed, 14.5 percent had mercury levels over 0.5 mg/kg (with a high of 1.62 mg/kg). Based on the Wayana's fish consumption patterns, adults were found to consume between 40 and 60 µg total mercury per day, nursing infants approximately 3 µg per day, children between 1 and 3 years of age 7 µg per day, between 3 and 6 years approximately 15 µg per day and between 10 and 15 years between 28 and 40 µg per day. Over half of the population had hair mercury levels over the WHO recommended level of 10 µg total mercury/g, with an average of 11.4 µg/g. (Mercury levels in the population of Guyana are approximately 3 µg/g and 1.7 µg/g in people from urban areas.)

4.5 Submitted data on mercury concentrations in fish

335. Information on mercury concentrations in fish in different parts of the world has been chosen in this report as an indicator illustrating the presence of mercury in the global environment. 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 in table 4.5. The available data illustrate that mercury is present all over the globe in concentrations that may affect human beings and wildlife.

336. As an illustration of how the observed concentration levels are related to potential adverse effect levels, **concentrations at or exceeding 0.3 mg/kg wet weight** – the US EPA Tissue Residue Criterion (at 17.5 gram fish intake/day) and the Japanese guideline value (see section 4.2.1) – have been **marked in bold text in the table**. These values represent the most recent comprehensive risk assessments regarding mercury exposure from fish diets. As mentioned in table 4.1, FAO/WHO Codex Alimentarius guideline levels for fish are 0.5 mg/kg wet weight for non-predators and 1 mg/kg wet weight for predators (such as shark, swordfish, tuna, pike and others).

Table 4.5 Examples of mercury concentrations in fish/shellfish in different regions of the world, as reported in submissions to the Global Mercury Assessment. Sample collection, treatment, and analysis methodology may vary and may have affected results. Consult references for details.

Geographic location	Fish and shellfish species	Concentration (-level) *3 ww: Wet weight *4 dw: dry weight *5	Year of sampling	Trophic level *1	Contamination level in habitat *2	References
Arctic area	Marine fish	0.01 - 0.1 mg/kg ww Peaks: 0.1 - **0.9** mg/kg ww	Various			AMAP, 1998
	Marine mussels	<0.009 - 0.033 mg/kg ww	Various			
Australia (southwest Tasmania)	Australian eel (Lake Gordon)	**0.86 – 2.15** mg/kg (mean **1.40** mg/kg, 9 samples)	1994			Bowles, 1998, in National submission from Australia, sub63gov
	Brown trout (Lake Pedder)	0.06 – **0.3** mg/kg (mean 0.16 mg/kg, 20 samples)	1993			
	Brown trout (Lake Gordon)	0.1 – **1.4** mg/kg (mean **0.35** mg/kg, 20 samples)	1994			
	Brown trout (Gordon River)	**0.3 – 2.35** mg/kg (mean 1.09 mg/kg, 25 samples)	1993			
	Redfin perch (Lake Gordon)	0.12 – **1.3** mg/kg (mean **0.52** mg/kg, 20 samples)	1993			
Baltic Sea	Round fish	0.010-0.050 mg/kg ww	1994-1998		Back	ICES, 1997, in Helcom, 2001
	Marine fish	0.016 - 0.091 mg/kg ww (muscle, all investigated species).			Gen	
	Blue mussel	0.005 - 0.010 mg/kg ww		Non	Back	
	Blue mussel	Slightly exceeding 0.01 mg/kg ww			Gen	

Geographic location	Fish and shellfish species	Concentration (-level) *3 ww: Wet weight *4 dw: dry weight *5	Year of sampling	Trophic level *1	Contamination level in habitat *2	References
Brazil	46 species from six trophic levels:		1991-1993			Boischio and Henshel, 2000
	Herbivore/Denitrivore	0.10/0.15 mg/kg (ww)				
	Planktophagus/Omnivore I	0.36/0.21 mg/kg (ww)				
	Omnivore II/Piscuvore	0.55/0.64 mg/kg (ww)				
Brazil (Amazonas)	River fish from pristine areas	Lower than 0.2 mg/kg ww of Hg	1990's		Back	Malm, as contained in NIMD Forum, 2001, in national submission from Japan (sub6govatt1)
	Predatory fish from contaminated areas (main mined Amazonas river basin)	Can reach levels of 2 – **6** mg/kg or more, Average values above **0.5** mg/kg		Pre	Con	
Côte d'Ivoire	Tuna species, "Thon Albacore" (Thunnus Albacares)	**0.30 - 0,36** mg/kg ww	1991	Pre	Gen	National submission from Côte d'Ivoire (sub72gov)
	Large individuals (80-91 kg):	**0.8** mg/kg ww (muscle)				
	Sole, "sole"	0.064 - 0,090 mg/kg ww		Non	Gen	
	Herring, "hareng"	0.037 - 0,047 mg/kg ww		Non	Gen	
Cyprus	Sword fish	0.20 - **2.00** mg/kg ww (mean **0.54** of 21 samples)	1993-1997	Pre	Gen	National submission from Cyprus (about 15 species reported in all)
	Sea bream	0.00 - **2.00** mg/kg ww (mean **0.38** of 42 samples)			Gen	
	Red mullet	0.00 - **0.70** mg/kg ww (mean 0.11 of 15 samples)		Non	Gen	
	Common dentex (dentex dentex)	0.00 - **2.00** mg/kg ww (mean 0.51 of 20 samples)			Gen	
Fiji	Shellfish (*Crassostrea mordax)*	<0.001-0.061 mg/kg ww	1987/88		Back	Naidu *et al.*, 1991
	Shellfish (*Crassostrea mordax)*	**0.55-0.95** mg/kg dw	1988		Con	Naidu and Morrison, 1994
	Shellfish (*Grafarium tumidum)*	0.05-0.20 mg/kg dw	1985/86		Back	Gangaiya *et al.*, 1988
	Shellfish (*Anadara spp.)*	0.037-0.099 mg/kg dw	1992/93		Back	Morrison *et al.*, 2001
	Canned tuna	0.01-0.97 mg/kg ww	1990/92		?	IAS, 1992
Finland	Northern pike in freshwater and brackish coastal waters	**1.52** mg/kg ww of Hg (average concentration)	1960's			Submission from the Nordic Council of Ministers, sub84gov
		0.60 mg/kg ww of Hg (average concentration)	1990			
France	Mussels (369 samples from 96 sampling stations along the coast of France	0.008 – 0.238 mg methylHg/kg dry weight (mean 0.064 mg/kg dry weight)	1996			Claisse *et al.*, 2001, in national submission from France, sub49gov
	Fish, Atlantic Sea:					Cossa, 1994 in national submission from France (sub49gov).
	Conger	1.2 +/- 0.3 mg/kg dw				
	Merlu	0.4 +/- 0.1 mg/kg dw				
	Rousette	2.0 +/- 0.6 mg/kg dw				
	Fish, Mediterranean Sea:					
	Conger	4.5 +/- 2.8 mg/kg dw				
	Merlu	3.2 +/- 2.1 mg/kg dw				
	Rousette	9.4 +/- 5.2 mg/kg dw				
	Fish caught in Baltic and North Sea, English Channel, Atlantic Ocean)		1971 – 1980			Thibaud, 1992 in national submission from France (sub49gov)
	Swordfish (*Xiphias gladius*)	Mean **0.780** mg/kg ww (41 samples)				
	Shark (*Lamna sp.*)	Mean **0.692** mg/kg ww (497 samples)				
	Red tuna (*Thunnus thynnus*)	Mean **0.470** mg/kg ww (344 samples)				

Geographic location	**Fish and shellfish species**	**Concentration (-level) *3 ww: Wet weight *4 dw: dry weight *5**	**Year of sampling**	**Trophic level *1**	**Contamination level in habitat *2**	**References**
Ghana	River species: Mostly “tilapia” (tilapia guineensis) and “catfish” (heterobranchus spp.)	General: **0,55 - 1,59** mg/kg ww Tilapia, mean: **1,17** mg/kg ww (of 8 fish)	2000		Con	National submission from Ghana and UNIDO report sub2igoatt6part2
Guam	Fish	0.009-0.045 mg/kg ww			Back	Denton *et al.*, 2001
Hong Kong	Mud carp (*Cirrhinus molitorella*)	0.025 mg/kg ww	1995			Dickman and Leung, 1998
	Freshwater grouper (*Micropterus sp.*)	0.195 mg/kg ww				
	Golden thread (*Nemipterus virgatus*)	0.219 mg/kg ww				
	Hair tail (*Trichiurus haumela*)	0.146 mg/kg ww				
India	18 groups of fish and other seafood in the Bay of Bengal, Arabian Sea and Indian Ocean	0.005-0.065 mg total Hg/kg (mean average values)			Back	Ramamurthy, 1979, in comments from India (comm.-13-gov)
	Bombay, west coast					Bhattacharya and Sarkar, 1996
	Fish	0.03-**0.82** mg total Hg/kg dw				
	Bivalves	0.13-**10.82** mg total Hg/kg dw				
	Gastropods	**1.05-3.60** mg total Hg/kg dw				
	Crabs	**1.42-4.94** mg total Hg/kg dw				
	Madras, southeast coast					
	Fish	Below detection limit (100 ng/g)				
	Fish	0.08-0.14 mg total Hg/kg ww				
	Sagar Island, east coast					
	Bivalves	0.06-**2.24** mg total Hg/kg dw				
Italy	Bluefin tuna (Thunnusthynnus thynnus)	0-4 mg total Hg/kg ww		pre	gen	Renzoni *et al.*, 1998
Japan	Scorpionfish,	**0.655** mg/kg ± 0.162	1978			Yasuda *et al*, in national submission from Japan, sub6gov
	inside Minamta Bay	**0.511** mg/kg ± 0.241	1993			
	Scorpionfish,	**0.603** mg/kg ± 0.216	1983			
	outside Minamata Bay	**0.531** mg/kg ± 0.194	1990			
		0.431 mg/kg ± 0.163	1999			
Kiribati	Shellfish (*Anadara spp.)*	<0.0001-0.006 mg/kg ww	1987		Back	Naidu *et al.*, 1991
Korea, Republic of	Unspecified freshwater fish species from 12 places each in Keum and Nakdong River Basins, respectively	Mean 0.126 mg/kg total Hg (10 species, 90 samples) Mean 0.196 mg/kg total Hg (6 species, 124 samples.	1989 1985			National submission from Korea (sub76govatt1)
	7 freshwater fish species(Givel, Carp, Grey mullet, Cat fish, Shake head, Eel, Mandarin fish) from Kangkyung area in Keum River	Mean **0.351** mg/kg (muscle, 7species, 57 samples)	1980			National submission from Korea (sub76govatt1)
	Freshwater fish species from 24 streams in South eastern area in Korea (Carassius auratus, Zacco temmincki, plecoglossus altivelis, Moroco lagowskii, Chaenogobius urotaenia urotaenia etc.)	0.02 – 0.12 mg/kg mean 0.07 mg/kg	1979			National submission from Korea (sub76govatt1)
Kuwait	Shrimp, various species	Not detected – 1.57 mg/kg (average less than 0.4 mg/kg)	1980's			Khordagui and Dhari, 1991, in UNESCWA submission, sub1igo

Geographic location	Fish and shellfish species	Concentration (-level) *3 ww: Wet weight *4 dw: dry weight *5	Year of sampling	Trophic level *1	Contamination level in habitat *2	References
Mauritius	Shark (unspecified)	0.13 - **0.60** mg/kg of Hg (52 samples of fresh shark)	?	Pre	Gen	National submission from Mauritius, sub56gov
	Marlin	**1.20 – 3.00** mg/kg of Hg (in 8 samples), 0.10-**0.90** mg/kg of Hg (in 18 other samples)				
	Tuna	0.10 – **0.70** mg/kg of Hg (16 samples of fresh tuna)				
	Swordfish	0.22 – **0.65** mg/kg of Hg (in 17 samples of swordfish)				
North East Atlantic (OSPAR waters)	Marine fish	0.01-0.2 mg/kg ww (general) Up to **0.9** mg/kg ww (peak areas)	1993-1996		Gen	OSPAR, 2000b and 2000, in submission from the Nordic Council of Ministers, sub84gov)
	Marine mussels	0.01-0.1 mg/kg ww(general) Up to **0.9** mg/kg ww (peak areas)		Non	Gen	
Norway	Pike	0.1 – **2.5** mg/kg	1988-1994			National submission from Norway, sub70gov
	Perch	0.1 – **2.5** mg/kg				
Philippines	Fish in river systems	0.00107 – **0.439** mg/kg totalHg 0.00071 – **0.377** mg/kg methylHg	1996-1999		Con (artisinal gold mining area)	National submission from Philippines, sub1gov
	Taiwan clam	0.233 -**1.208** mg/kg total Hg	1997-1999	Non		
	Tilapia	0.109-**0.494** mg/kg total Hg	1996-1999			
Seycelles	Various ocean species	Mean of 0.2-**0.3** mg/kg				Cernichiari *et al.*, 1995, as quoted by Pirrone *et al.*, 2001
Slovak Republic	Some river and lake species:					Comments from Slovak Republic (Comm-14-gov)
	Barbel (*Barbus barbus*)	0.053-**7.329** mg/kg ww (mean 0.728 mg/kg, 29 samples)	1995-2000			
	European perch (*Perca fluviazlis*)	0.009-**1.964** mg/kg ww (mean 0.212 mg/kg, 34 samples)	1995-2000			
	Grayling (*Thymallus thymallus*)	0.032-0.110 mg/kg ww (mean 0.064 mg/kg, 6 samples)	1995-1997			
	Rainbow trout (*Salmo gairdnerii*)	0.001-**0.970** mg/kg ww (mean 0.038 mg/kg, 56 samples)	1995-2001			
	Eel (*Anguilla anguilla*)	0.007-0.220 mg/kg ww (mean 0.093 mg/kg, 8 samples)	1995-1996			
Solomon Islands	Fish flesh (spp. Unknown)	0.0002-0.0014 mg/kg ww			Back	Kannan *et al.*, 1995
	Fish liver (spp. Unknown)	0.089-0.120 mg/kg ww				
Sweden	Northern pike of one kilogram in inland waters	0.1-**2.0** mg/kg ww				Comments from Sweden (Comm-12-gov)
Taiwan	Blue marlin (*Makaira mazara*)	**10.3** mg/kg dw	1995-1996			Han *et al.*, 1998
	Tuna (*Thunnus albacores*)	**9.75** mg/kg dw				
	Grass shrimp (*Penaeus mondon*)	**2.19** mg/kg dw				
	Oyster (*Crassostrea gigas*)	0.180 mg/kg dw				
Thailand	Unspecified fish, shrimp and shellfish species at 15 different river mouths (caught with "artisanal gear")	0.041-**0.32** mg/kg (dw)	1998		Gen	National submissions from Thailand, sub53gov
		0.01-**0.6** mg/kg (dw)	1999			
	Snapper, Grouper, Threadfin bream, Lizard fish, Cobia	0.049 – **0.694** mg/kg (ww)	1997			Windom and Cranmer, 1998

Geographic location	Fish and shellfish species	Concentration (-level) *3 ww: Wet weight *4 dw: dry weight *5	Year of sampling	Trophic level *1	Contamination level in habitat *2	References
Tonga	Shellfish (*Grafarium tumidum)*	0.022-0.191 mg/kg ww	1987		Back	Naidu *et al.*, 1991
United Kingdom (Irish Sea)	Flounder (*Platichthys flesus*) caught close to Ireland, Wales, Isle of Man	0.008 – **0.331** mg/kg ww	?			Leah *et al*, 1992 in national submission from United Kingdom, sub39govatt1
	Flounder caught close to Liverpool Bay	Up to **1.96** mg/kg ww				
	Plaice (*Pleuronectes platessa*)	Less than **0.5** mg/kg ww				
	Dab (*Limanda limanda*)	Less than 1.1 mg/kg ww				
	Lesser spotted dogfish (*Scyliorhinus caniculus*)	Less than **2.5** mg/kg ww				
United Kingdom	Eels (*Anguilla anguilla*)	0.001 – 0.082 µg/kg (mean 20)	?			Downs *et al.*, 1999 in national submission from United Kingdom, sub39govatt1
	Caught in various East Anglia locations	0.014 – 0.788 µg/kg (mean 170) 0.022—0.168 µg/kg (mean 82)				
United Kingdom	Survey of 336 fresh/frozen/processed sea fish and shellfish -					University of Bristol Survey - Mercury in imported fish and shellfish and UK farmed fish and their products, unpublished, posted at www.food.gov.uk/multimedia/pdfs/Mercury_in_Fish_table.pdf
	Halibut	0.038-**0.617** mg/kg (mean 0.290, 2 samples)				
	Marlin	**0.409-2.204** mg/kg (mean **1.091**, 4 samples)				
	Shark	**1.006-2.200** mg/kg (mean **1.521**, 5 samples)				
	Swordfish	**0.153-2.706** mg/kg (mean **1.355**, 17 samples)				
	Tuna	**0.141-1.500** mg/kg (mean **0.401**, 34 samples)				
United States of America	Bottom feeders –		1990-1995	Non		US EPA, 1997
	Carp	0.061 –0.250 mg/kg				
	Channel catfish	0.010 - **0.890** mg/kg				
	White sucker	0.042 - **0.456** mg/kg				
	Predators –			Pre		
	Smallmouth bass	0.094 - **0.766** mg/kg				
	Brown trout	0.037 - **0.418** mg/kg				
	Largemouth bass	0.101 - **1.369** mg/kg				
	Walleye	0.040 - **1.383** mg/kg				
	Northern pike	0.084 - **0.531** mg/kg				
Vanuatu	Shellfish (*Anadara spp.)*	0.02-0.04 mg/kg ww	1987		Back	Naidu *et al.*, 1991
	Shellfish (*Crassostrea mordax)*	0.01-0.04 mg/kg ww	1987			

Notes:

1 Indication of trophic level: **Pre** - predator/higher level; **Non** - non-predator/lower level;

2 Indication of contamination level in habitat: **Gen** - general/unspecified; **Back** - background level; **Con** – contaminated.

3 Unless otherwise mentioned, it is assumed that the results refer to measured content of total mercury (and not methylmercury).

4 Mercury concentration may be assumed to be wet weight (ww) unless otherwise indicated.

5 Dry weight results will by definition be higher than wet weight result (because of the water content in fish and seafood), and is therefore not directly comparable to wet weight results and guideline values based on wet weight.