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Children's health and mercury exposure

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Abstract
The reason why mercury is dangerous is that once released into the environment it cannot be removed and is rapidly transformed by microorganisms into organic compounds that tend to bioaccumulate and biomagnify in animals. The principal organic compound is methylmercury (MeHg). The primary route of exposure to MeHg for humans is consumption of fish. The safe dose (reference dose, RfD) of MeHg that can be consumed without neurotoxicological consequences is 0.1 µg per kg b.w./day. According to available data, the whole population of certain European countries or people who consume large quantities of fish are exposed to doses of MeHg that exceed the RfD. Given this level of mercury exposure, in order to avoid or reduce the expected neurotoxic consequences on foetuses we propose the following strategy:
1) At present the most reasonable solution for pregnant women (and small children) is to reduce substantially or completely avoid fish intake.
2) In the medium term the European Community should evaluate the technical and economic feasibility of breeding uncontaminated fish in order to reduce the drawbacks of banning fish consumption.
3) In the long term there is no alternative to substantially reducing mercury emissions worldwide.

Key Words: *Children, methylmercury, fish consumption, European Community*

Introduction

Mercury is released by both natural and anthropogenic sources. The anthropogenic component of mercury deposition considerably exceeds the natural component; the EU produces 1000 tonnes of the current global supply of 3600 tonnes of mercury per year. This is mainly the surplus of the electrochemical chlor-alkali industry (coal-fired power plants) and the recycling of waste materials, such as dental amalgam, thermometers and fluorescent light tubes. Compared with natural levels, anthropogenic activities are thought to have increased atmospheric levels of mercury by roughly a factor of three [1–3].

Past releases have created a 'global pool' of mercury in the environment, part of which is continuously mobilized, deposited on land and water and remobilized. Initially seen as an acute and local problem, mercury pollution is now deemed global, diffuse and chronic [1].

Mercury is dangerous because once released in the environment it cannot be removed. When the elemental Hg and its inorganic compounds reach a watery environment they are rapidly transformed by microorganisms into organic compounds, mainly methylmercury (MeHg). Because ingested mercury is rapidly and completely absorbed, MeHg tends to bioaccumulate and biomagnify in animals reaching very high concentrations (up to more than 2 mg per kg) in large fish or mammals at the end of the food chain. Populations with a high intake of fish and seafood are therefore particularly vulnerable [1].

Many industrialized nations have established procedures and policies to assess, minimize, and prevent toxic mercury exposure in the milieu and diet, but in general little is known about compliance with the health authorities' recommendations especially for diet [4,5].

This paper attempts to put in perspective the health problems deriving from the current level of mercury exposure in children.

Sources of exposure

Elemental mercury

Elemental mercury is liquid at room temperature and rapidly turns into vapour when heated. Seventy per cent of the atmospheric emission from anthropogenic sources comes from stationary combustion of coal and incineration of waste materials (especially medical waste). Because combustion of fossil fuels is increasing in order to meet the growing energy demands, atmospheric mercury emission can be expected to increase [6]. Although control technologies for coal combustion plants and waste incineration may provide some level of mercury control, they currently reduce only a small amount of mercury from these sources. Optimized technologies for reducing the release of mercury are being developed but are not yet commercially available [1–3].

Another important source of environmental contamination is dental amalgam. This compound (50% mercury) is a good material for filling the cavities provoked by dental caries. Its use in dentistry is nevertheless declining, mainly because prevalence rates of caries are decreasing and more aesthetically and functionally valid substitutes (resins with metals incorporated) are available, and also because the health authorities have imposed strict rules for the removal of amalgam. The amount of mercury deposited in the teeth of the European population (EU + EFTA States) has been estimated to be 1300–2200 tonnes, the largest mercury stockpile in our society after that of the stock of the clor-alkali industry [6]. Of the 350 tonnes of annual EU mercury consumption, 70 tonnes (20%) is represented by amalgam [7]. This percentage will tend to increase as the Hg used in clor-alkali, electrical and other industries continues to decline. Although amalgam waste from dental care is stipulated by EU waste legislation as hazardous waste, the use of the supports necessary to accomplish these regulations (e.g. use of filters and separators in dental practice, availability of proper waste collection by trained personnel, and methods used in crematoria) is probably lacking in a number of EU member states [1]. Other expendable products containing mercury are fluorescent light bulbs, thermometers and batteries. Inappropriate disposal of all these items is a major source of environmental contamination when they are buried under the ground or burned in waste incinerators [2]. Another source of elemental and inorganic mercury is the folk remedies used around the world [8].

Inorganic mercury compounds

Inorganic mercury compounds have been used for decades in numerous products including skin creams, medications, and soaps and many are still in use today. Another concern is the number of females, possibly of childbearing age, using skin preparations. Because inorganic mercury compounds can be absorbed through the skin, the use of these creams can have serious implications for the foetus [8]. If ingested, about 10% of mercury salts are absorbed [9].

Organic mercury compounds

Three organic compounds of mercury are being produced as biocides and pesticides:

1) MeHg is the predominant and most toxic form of organic mercury found in the environment. It is mainly formed through bacterial metabolism of mercury present in the air or discharged into water from natural or human sources. When ingested MeHg is rapidly and completely absorbed in tissues where it establishes sulfhydryl bonds with proteins and in this form has a half-life of more than two years. If the contaminated proteins are digested by another animal, MeHg again becomes available for absorption. It therefore tends to bioaccumulate and biomagnify in animals; in large fish or mammals at the top of the food chain it may reach exceedingly high concentrations [1].

The primary route of MeHg exposure in humans is consumption of fish. The mercury concentrations in various fish species generally range from about 0.05 to 1.4 milligrams per kilogram of fish tissue, depending on the species, age and size of the fish. Fish higher in the food chain (or of higher trophic level) tend to have higher levels of mercury. Hence, larger predatory fish, such as king mackerel, pike, shark, swordfish, walleye, barracuda, large tuna, scabbard and marlin, as well as seals or whales, contain the highest concentrations [2]. MeHg is neurotoxic at all ages, and the developing foetal brain is at least 10-fold more sensitive than the adult brain [10,11].

2) Ethylmercury (EtHg) is an organic Hg compound which in the form of thimerosal has been used as a topical antiseptic and as a preservative in vaccines routinely given to children, including diphtheria-tetanus-acellular pertussis (DTP), hepatitis B, and Haemophilus influenzae type b [12,13]. Thimerosal contains 49.6% Hg by weight and is metabolized to EtHg and thiosalicylate. When used in paediatric vaccines each dose contains about 12.5–25 μg Hg per 0.5 ml (hepatitis B vaccine contains 12.5 μg mercury per 0.5 ml dose, DTaP or DTP: 25 μg mercury, and Hib vaccine: 25 μg mercury). Depending on vaccine formulation and schedule, an infant

may receive a total mercury dose from vaccines as large as 187.5 μg during the first six months of life. In certain populations, influenza vaccine may be administered at six months of age, thus increasing the total dose to 200 μg. After a single dose of thimerosal-containing hepatitis B vaccine, Stajich et al. [14] found that prevaccination blood Hg levels increased from 0.54 to 7.36 Hg/l in 15 preterm infants, and from 0.04 to 2.24 Hg/l in five term infants. Anti-tetanus and anti-influenza Hg-containing vaccines might be more damaging than vaccinations in infancy if administered to childbearing women.

Thimerosal has been removed from most vaccines in the United States, but is still used in some developing countries. Various health authorities within the EU have encouraged the use of Hg-free vaccines and in practice the use of vaccines containing Hg is rapidly declining. No precise regulations, however, have been issued at EU level.

3) Phenylmercury is less toxic than MeHg and EtHg. It was used as a fungicide in latex paints but is no longer used in Europe.

Toxicology

The molecular mechanisms underlying MeHg-induced cellular toxicity are incompletely understood. As a general rule, the biochemical toxicity of MeHg and other mercurials is attributed to its extremely high affinity for protein sulfhydryl groups [15]. Because the common role for disulfide bond formation is that of stabilizing tertiary structures, protein structure or enzyme function may undergo non-specific changes after interactions between MeHg and cysteine sulphur groups. The non-specific nature of the interaction between MeHg and cellular macromolecules makes it unlikely that a single underlying event is responsible for the myriad of effects observed upon MeHg exposure. Faustman et al. [16], however, believe that the effects of MeHg on sulfhydryl protein groups may not be sufficient to explain the observed effects of this compound on the cell cycle. These investigators suggest a strong effect of MeHg on intracellular bivalent cation regulation and consider an impairment of calcium homeostasis in the cell cycle the primary noxious event for nerve cells. Cells regulate the intracellular calcium concentration through many pathways. Experimental data support a model where MeHg exposure leads to a sustained elevation in calcium concentration through alteration in calcium permeability and mobilization of calcium stores. This calcium increase could activate cytolytic enzymes, protein-kinases and dysfunction of calcium-dependent proteins. The toxic effects of MeHg on central nervous system tissues have been documented in laboratory and animal studies (Table I) [17,18]. MeHg is easily transported across the placenta and

Table I. The toxic effects of MeHg on central nervous system tissues demonstrated in laboratory and animal studies [17,18].

Biological effect	Experimental Hg tissue Concentration
Extensive, early onset necrotic neuronal death	1–2 μg/g
Apoptosis of cerebellar granule cells	0.2 μg/g
Cytoskeletal components (especially microtubules) fragmentation and neuronal net dissolution	0.2 μg/g
Inhibition of neuronal migration (dose dependent)	0–2 μg/g
Increase of intracellular Ca + + concentration	0.1 μg/g
Cell damage and death by Hg induced increase of reactive oxygen compounds causing oxidative stress Inhibition of neuron uptake of glutamic acid	0.2 μg/g
Increase of muscarinic-colinergic receptors in hippocampus and cerebellum (dose dependent) Down-regulation of dopamine D-2 receptors in males	0.5 μg/g
Inhibition of spontaneous neuronal differentiation of cultured neural stem cells	0.5–1 mg/l

the blood-brain barrier and is preferentially stored in brain and CNS; over time brain levels may exceed blood levels by three to six times.

Health consequences

A characteristic of acute MeHg poisoning is the long latency between exposure and the onset of clinical symptoms. In a well-documented case of acute accidental severe poisoning no symptom was observed for 150 days before full neurological symptoms developed and death occurred [19]. Contrary to what could be intuitively expected, and still scientifically unexplained, is the fact that in cases of acute poisoning the latency period is longer in subjects who receive higher doses [19].

Latency periods associated with low level chronic exposure are substantially longer – up to 15 years in humans exposed in the Minamata disaster (1950s) and seven years in monkeys poisoned during the first seven years of life. In chronic exposure the latency period is directly dose dependent. In Iraq (1972) the half-life of elimination was found to vary from 40 to 105 days. Owing to the high variability in sensitivity to Hg, there is no certainty that the same dose will induce the same signs and symptoms in two different individuals; again in Iraq, the body burden in which paraesthesia in adults could be detected varied from 25 to 200 μg [19]. In the tragic incidents of Minamata and Iraq, infants born to contaminated mothers

manifested a variety of neurological impairments (from severe mental retardation or cerebral palsy to subtle delays in walking and talking), whereas their mothers suffered minimal symptoms or none. MeHg is now considered neurotoxic at all ages, and the developing foetal brain is at least 10-fold more sensitive than the adult brain [10].

Epidemiological studies on the health effects of *in utero* exposure to methylmercury belong in three groups.

Historic cases of collective poisoning

Minamata/Niigata episodes during the 1950s in Japan. 'Congenital Minamata disease' was described in children after the exposure of the mother during pregnancy through consumption of highly contaminated fish. No quantitative measure of exposure is available, hence no dose-response relationship.

Iraq, winter 1971–72. Grain seeds treated with a fungicide containing mercury which were supposed to be planted, were used for making bread. Possibly 50 000 persons were exposed; 6350 patients were admitted to hospitals and 459 died. Exposure was carefully documented by a team from the Rochester School of Medicine, who conducted a study of prenatal exposure in mothers who were pregnant during the poisoning in relation to developmental outcomes in their children. A dose-response curve suggested that prenatal exposure sufficient to cause a biological damage was associated with a mercury concentration of 10 ppm in maternal hair [20]. This maternal exposure can be estimated to have been 1 μg/kg of body weight/day.

Small scale studies

Several cross-sectional studies of populations exposed to chronic low levels of MeHg have been published during the past 20 years. Most of them show effects, with a variety of endpoints: delayed auditory and visual evoked potentials, decreased psychomotor performances [21], abnormal or questionable results in some scholastic and psychological tests [17], increased deep tendon reflexes, poorer coordination of the legs, decreased performance in the Stanford-Binet copying score, and lower scores in the linguistic pathway of neurodevelopmental screening [22]. Some published studies found no associations [23].

Large scale longitudinal cohort studies

Faeroe Islands. Nine hundred and seventeen out of 1022 children born in the Faeroe Islands between March 1986 and December 1987 were assessed at age seven years. Each child went through five hours of detailed examination. This study showed several neuropsychological deficits associated with MeHg levels in cord blood [21,24,25].

Republic of Seychelles. Seven hundred and seventy-nine mother-infant pairs were enrolled in 1989–90 when the children were six months old. The children were assessed with several tests for neurocognitive, language, memory, motor, perceptual-motor, and behavioural functions at ages six months (740 children analysed), 19 months (738), 29 months (736), 66 months (711) and nine years (643). No detectable adverse effects were found in relation to MeHg levels in maternal hair grown during pregnancy [23,26]. The differences between the results of the last two studies have been tentatively explained; in the Seychelles study, exposures resulted entirely from daily fish consumption. In the Faeroes, exposure was attributable mainly to pilot whale meals consumed episodically. Pilot whales have much higher levels of mercury than typical ocean fish and also contain other contaminants such as polychlorinated biphenyls (PCBs). Exposure to MeHg in conjunction with other components of fish such as selenium and amino acids may also influence its potential toxicity. In addition, ocean fish may provide important nutrients (such as omega-3-fatty acids) which may improve brain performance to such an extent that any adverse effects from low levels of MeHg are not apparent.

MeHg Exposure of children in Europe and impact evaluation

Calculating the lowest mercury exposure causing harmful effects is a complex task and can be influenced by the variables taken into consideration (e.g. the number and quality of the confounders, degree of uncertainty in the measures of both the concentration of the toxic substance in body tissues and performance in the biological tests applied, and concomitant exposures to other substances). Innumerable papers and reports issued by governmental and international committees have nevertheless reached consensus on the following issues. The benchmark dose levels (BMDL) – the concentration of mercury in the hair of mothers at the end of the pregnancy which increases from 5 to 10%, the percentage of children in the first decade of life with abnormal response to tests measuring various endpoints, including delayed auditory evoked potentials, psychomotor performances, abnormal findings on psychological tests, and low scores in neurodevelopmental screening – range from 6 to 12–15 μg/g of hair. These benchmark levels correspond to maternal exposures of about 1 μg/kg b.w./day of MeHg. Based on these two factors several agencies have applied toxicological limits for the 'tolerable daily intake' or

'reference dose' (RfD) of methylmercury ranging from 0.1 μg/kg b.w./day [27] to 1.6 μg/kg b.w./week [28]. In 2001, a group of European scientists evaluated the risks from mercury exposure in Europe and presented their view in their 'Position Paper on Mercury' [29]. They recommended that the US EPA RfD for MeHg should apply also in Europe.

A US EPA RfD of 0.1 μg per kg b.w./day must therefore be considered appropriate for Europe. Some studies have suggested that each doubling of prenatal MeHg exposure, starting from around this RfD of 0.1 μg per kg b.w./day leads to a loss in IQ of about 1.5 points. This finding implies that prenatal exposure

around the BMDL of 1 μg/kg b.w./day of MeHg would equate to an IQ loss of about 6 points.

Figure 1 shows the maternal hair and blood concentrations and neonatal cord blood and brain concentrations (axes 2–4) expected from two levels of permanent maternal exposure (0.1 and 1 μg/kg b.w./day, axis 1).

The horizontal lines crossing all the axes represent the RfD established by US-NRC 2000 (0.1 μg/kg b.w./day) and accepted also for the EU [28] and two BMDLs (the exposure levels, calculated from existing data, which are expected to cause clinical consequences).
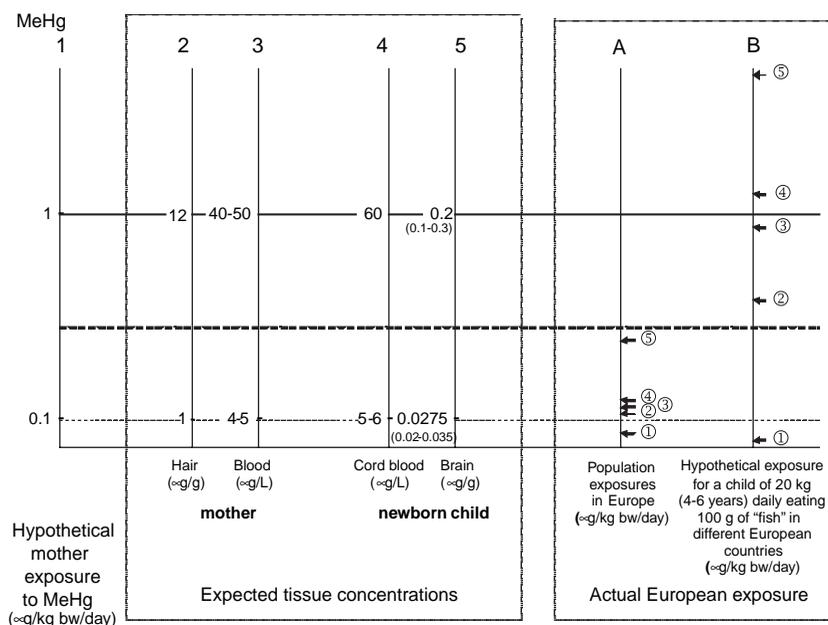

Figure 1.

------ Reference dose US-EPA, 2001 (0, 1 μg/kg b.w./day) also accepted for Europe.

----- 6 μg/g: bench mark dose level (BMDL) calculated for the Faeröe study, including in a structural equation model all exposure information confounders, cognitive outcomes and measurements uncertainty (Budtz-Jørgensen et al., 2003, 2004).

——— 10.3 μg/g: BMDL in a linear model for brain auditory evoked potentials, Peak III Latency at 20 Hz in Faeröese and Madeirian children (Murata et al., 2002). Very similar to this (12 μg/g) is the BMDL for the Faeröese study calculated by the Joint FAO/WHO Expert Committee on Food Additives for the linear dose response model taking in account several different brain functions (and not the most sensitive ones) (JECFA, 2003).

Axes 1–5: Relationship between exposure (Axis 1) and Hg concentration in different body compartments (Axes 2–5).

A axis: Exposure (μg/kg b.w./day) of European populations to MeHg (Scoop, 2004).

① 0.05   Mean intake of adults in 13 European countries
② 0.12   Mean intake of adults in Italy
③ 0.187   Mean intake of general population in Portugal
④ 0.189   Mean intake of adult high-level consumers in Belgium and Germany
⑤ 0.486   Mean intake of adult high-level consumers in Norway

B axis. Exposure to MeHg (μg/kg b.w./day) for a child weighing 20 kg eating 100 g of 'fish'/day in different European countries (Scoop, 2004).

① 0.02   United Kingdom
② 0.627   Greece
③ 0.945   Germany
④ 1.075   Italy
⑤ 1.6   Portugal.

Concern derives from the fact that Hg concentrations observed in the blood of pregnant women and newborns when they assume 0.1 µg/kg b.w./day, the most conservative of the reported Hg RfD, are of the order of, or superior to, the concentrations reported to cause neurological damages in laboratory or animal experiments (Table I).

The A axis in Figure 1 displays the MeHg exposures in the European adult populations derived from the data of the Scoop Study on Hg content and intake of fish, fish products, bivalves, cephalopods, crustaceans and squid in 13 European countries. Because about 80–90% of all the mercury present in fish is generally assumed to be MeHg, the content of Hg in fish has been considered to be MeHg [30]. According to available data in Scoop, the estimated adult mean weight (males and females) is 70 kg. If we consider that these data represent the real situation, and we have no reason not to do so, we must conclude that the populations of certain countries are as a mean exposed to doses of MeHg that exceed the RfD and are associated with blood Hg concentrations of the order of those found to be harmful (Table I). Also, the general mean MeHg consumption in the 13 studied EU countries, about half of the RfD, implies that, depending on the Gaussian distribution of individual exposures, a significant proportion of the European people are overexposed to this toxic metal. 'Consumers' or 'high level consumers' are obviously even more overexposed than others.

For most of the European countries specific data on the daily intake of MeHg in children are missing in Scoop, but as the report itself suggests, since children consume higher quantities of food per kg body weight than adults, their body burden of MeHg per kg b.w. will generally be larger than that of adults. Accordingly, in Germany and France where data are available for both adults and children, the MeHg intake per kg of b.w. is always higher in children (Germany: adults 0.04 µg /kg b.w./day; children aged 4–6 years, 0.061 µg/kg b.w./day; children aged 10–12 years, 0.050 µg/kg b.w./day; France: adults 0.041 µg/kg b.w./day; children aged 3–14 years, 0.050 µg/kg b.w./day). Hence the daily MeHg intake of European children as a general mean is presumably similar or superior to the adult general mean value of 0.05 µg/kg b.w./day.

In the foregoing calculations we assumed that all mercury contained in fish is MeHg (a possible overestimation of 20%), but we did not consider the amount of mercury ingested with foods other than fish, for example with water, vaccines and dental amalgam or inhaled with air. Moreover, the data reported in Scoop on food consumption in the various European countries are largely incomplete. The real exposure of European children to MeHg could therefore be worse than the reported data lead us to expect. If the different risk factors (such as living in a country with high exposure, belonging to a family with high fish consumption, and being a child) coincide in the same person, then exposure will be unacceptably high. For example, the estimated level of mercury exposure for a European child weighing 20 kg with a regular daily intake of 100 g of 'local' fish ranges from 0.02 to 1.6 (16 times the RfD!) µg/kg b.w./day (Figure 1, B axis).

In conclusion, notwithstanding the scarce data on child exposure to MeHg [29], children are more exposed than the general adult population. A large percentage of children, especially in certain countries (e.g. Italy and Portugal), are probably exposed to MeHg levels exceeding the RfD. Fractions of the adult population (including pregnant women) in all countries may also be exposed to levels exceeding the RfD, according to the amount and the type of routine fish consumption. These levels of foetal and childhood exposure, and the expected consequent brain tissue concentrations come within the range found in epidemiological and experimental studies associated with negative outcomes.

Proposed actions

A key long-term aim is to reduce levels of mercury in the environment to a point that would eliminate concern over MeHg in fish. The best way to achieve this end is to reduce anthropogenic mercury releases into the environment, either through measures aimed at controlling emissions directly, or through measures at earlier stages of the mercury cycle such as supply and use.

In considering, together with the ethical and medical consequences of MeHg exposure, the economic impact of measures aimed to reduce mercury release, enlightening information comes from the study conducted by Trasande et al. (2005) [31]. Using national blood mercury prevalence data from the Centers for Disease Control and Prevention, these investigators found that given the current number of US newborn having a cord blood mercury level of >5.8 µg/l, a level associated with loss of IQ, the cost of methylmercury toxicity can be estimated to be $8.7 billion annually (range $2.2–43.8 billion; all costs being in 2000 US$). Of this total, $1.3 billion (range $0.1–6.5 billion) each year is attributable to mercury emissions from American power plants. Data from Europe, if available, would probably differ little.

The EC has already done much to reduce mercury emissions and uses. Even if some measures and recommendations have not taken full effect or have not yet been applied, intentional use of mercury has dropped substantially in the EU in recent decades and is continuing to fall owing to EC legislation already

enacted. Further policies have been planned and will be applied in the near future [1].

The mercury problem, however, has a significant global dimension which cannot be solved by the EU acting alone. In the medium and long term, emissions from outside Europe appear likely to grow in absolute and relative terms. For example, overall emissions to air in Europe decreased by 60% from 1990 to 2000, while global emissions rose by 20% over the same period [32]; as a result the European share of the total global mercury emissions to air fell from 33% to 5% in 2000. However, even if first deposited outside Europe, mercury products may subsequently be remobilized and recirculated as part of the 'global pool'.

Given the present situation, clearly there is no more room for further mercury pollution and there is an urgent need for international action to reduce mercury emissions.

The EU could certainly take further actions aimed to reduce the effects of population exposure to Hg. The first point is to consider that the question of Hg pollution is a dynamic process under the influence of several factors including continuous industrial development, new demand for sources of energy including the resurgence of coal activated plants, and uncontrolled use of Hg-containing chemicals.

A large body of research is necessary to monitor and define better the present situation, mainly addressing the exposure of special groups of EU populations, the genetic components influencing the adverse effects of Hg on health, and the interactions with other pollutants and with environmental factors, including socioeconomic conditions.

Another mercury product we have already mentioned is dental amalgam. Amalgam is an important source of Hg environmental contamination not only because it could cause damage to human health, but also for the simple reason that it represents 20% of the EU Hg consumption. It is surprising that the EU has seen fit at great expense to regulate amalgam as a hazardous waste (not only in the field of dentistry but also Hg emission in the air from crematoria), yet has left unregulated its production and use. The first steps towards banning amalgam completely should be to regulate and reduce its use, at the same time encouraging production of the existing suitable substitutes.

The problem of thimerosal-containing vaccines seems almost resolved in the EU where they are now rarely used in children. They are, however, not forbidden. Hence they could still be dangerous if used in women during pregnancy, similar to anti-tetanus and anti- influenza vaccines. Their use in pregnancy might be even more damaging than vaccinations in infancy.

Fish consumption for childbearing women and children

The foregoing observations underline that the long-term aim of protecting human health from the mercury already released into the environment and continuously produced within and outside the EU, will be a lengthy undertaking. The present environmental levels of mercury reflect past mercury emissions since the industrial revolution. Even without further emissions it would probably take decades for these levels to fall.

In the meantime, we must rely on interim protective measures mainly concerning fish consumption advisories. The EU has set a maximum allowable level for total mercury of 0.5 mg/kg for fishery products and a separate maximum level of 1 mg/kg for certain fish species (Regulation 466/2001 of 8 March 2001, setting maximum levels for certain contaminants in foodstuffs, OJ L 77, 16.03.2001, as amended by Commission Regulation 221/2002 of 6 February 2002, OJ L 37, 7.02.2002), although these levels are presently under review. With a weekly intake of about 200 g (one fish meal) of fish with, e.g. 0.4 mg/kg, a woman weighing 60 kg would receive an amount of methylmercury twice as high as the RfD.

For those fish species that can be marketed even if the MeHg level is 1 mg/kg, the same 60 kg woman (fewer meals are recommended for lower body weights) can consume less than one meal of fish per month if the RfD is not to be exceeded.

The most reasonable solution is therefore to set advisory limits designed to encourage pregnant women and small children to reduce substantially, or completely avoid, fish intake [1].

Obviously this decision would have several drawbacks. Fish is a valuable dietary component for both adults and children, being a rich source of proteins, vitamins (D and E), trace elements (selenium, fluoride and iodine) and one of the most important sources of omega-3 fatty acids. In pregnancy and lactation there is a demand on the mother to supply the foetus and infant with these compounds, which are required for the development of the central nervous system. Some evidence suggests that increased maternal intake of omega-3 fatty acids produces beneficial effects, especially in lower birth-weight populations. This benefit may be greater in populations that tend to have a lower background intake of fish. Hence the use of supplements or fortified foods as substitutes for fish may not be the ideal solution. A possible reason why the Seychelles study found that a high consumption of fish containing moderate amounts of Hg did not lead to clinically negative outcomes could be that, in that setting, benefits derived from fish balanced the risks. Highly important are the economic and commercial conse-

quences deriving from substantial limitations of fish consumption. Moreover, for some populations, locally caught fish may be the only good option for a nutritious diet.

We believe that to avoid depriving pregnant women of these advantages of fish consumption, and to reduce the negative impact of banning fish consumption, we need to evaluate the technical and economic feasibility of producing uncontaminated breeding fish.

'Aquaculture' is intended as the process of rearing or culturing aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural conditions of the environment [33,34]. As several specific reports outline, this industrial area suffers from several technical and ecological problems. Many of these could be overcome if the main difficulties, i.e. low market demand, excessive production and supply, and associated price reductions, could be resolved. Aquaculture, especially methods using fresh water and 'suitable' industrial feed for the animals, can produce fish almost completely free of mercury and other toxic contaminants, e.g. PCBs. As well as providing, whenever necessary, a simple alternative to the traditional fishing industry, aquaculture could prove a useful strategy for producing less contaminated fish.

Acknowledgements

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