UNITED NATIONS
ENVIRONMENT PROGRAMME

CHEMICALS

GLOBAL MERCURY ASSESSMENT

A drop of mercury

IOMC INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

A cooperative agreement among UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD

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Issued by UNEP Chemicals

Geneva, Switzerland

December 2002

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This publication has been developed with the support of
the International Bank for Reconstruction and Development.

This publication is produced within the framework of the
Inter-Organization Programme for the Sound Management of Chemicals (IOMC).

The ***Inter-Organization Programme for the Sound Management of Chemicals (IOMC)****, was established in 1995 by UNEP, ILO, FAO, WHO, UNIDO and OECD (Participating Organizations), following recommendations made by the 1992 UN Conference on Environment and Development to strengthen cooperation and increase coordination in the field of chemical safety. In January 1998, UNITAR formally joined the IOMC as a Participating Organization. The purpose of the IOMC is to promote coordination of the policies and activities pursued by the Participating Organizations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.*

This document is available from:

UNEP Chemicals
11-13, chemin des Anémones
CH-1219 Châtelaine, Geneva
Switzerland
Phone: +41 22 917 1234
Fax: +41 22 797 3460
E-mail: chemicals@unep.ch
Website : http://www.chem.unep.ch

UNEP Chemicals is a part of UNEP's Technology, Industry and Economics Division

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Key findings of the report

WHY SHOULD WE BE CONCERNED AND CAN INTERVENTION RESULT IN CHANGE?

Mercury is Present throughout the Environment

1. Environmental mercury levels have increased considerably since the on-set of the industrial age. Mercury is now present in various environmental media and food (especially fish) all over the globe at levels that adversely affect humans and wildlife. Widespread exposures are occurring due to human-generated sources, and past practices have left a legacy of mercury in landfills, mine tailings, contaminated industrial sites, soils and sediments. Even regions with no significant mercury releases, such as the Arctic, are adversely affected due to the transcontinental and global transport of mercury.

Mercury is Persistent and Cycles Globally

2. The most significant releases of mercury pollution are emissions to air, but mercury is also released from various sources directly to water and land. Once released, mercury persists in the environment where it circulates between air, water, sediments, soil and biota in various forms. Current emissions add to the global pool– mercury that is continuously mobilised, deposited on land and water, and re-mobilised.

3. The form of mercury released varies depending on source type and other factors. The majority of air emissions are in the form of gaseous elemental mercury, which is transported globally to regions far from the emissions source. The remaining emissions are in the form of gaseous inorganic ionic mercury forms (such as mercuric chloride) or bound to emitted particles. These forms have a shorter atmospheric lifetime and will deposit to land or waterbodies within roughly 100 to 1000 kilometres of their source. Elemental mercury in the atmosphere can undergo transformation into ionic mercury, providing a significant pathway for deposition of emitted elemental mercury.

4. Once deposited, the mercury form can change (primarily by microbial metabolism) to methylmercury, which has the capacity to collect in organisms (bioaccumulate) and to concentrate up food chains (biomagnify), especially in the aquatic food chain (fish and marine mammals). Methylmercury is therefore the form of greatest concern. Nearly all of the mercury in fish is methylmercury.

Mercury Exposure Has Serious Effects

5. Mercury has caused a variety of documented, significant adverse impacts on human health and the environment throughout the world. Mercury and its compounds are highly toxic, especially to the developing nervous system. The toxicity to humans and other organisms depends on the chemical form, the amount, the pathway of exposure and the vulnerability of the person exposed. Human exposure to mercury can result from a variety of pathways, including, but not limited to, consumption of fish, occupational and household uses, dental amalgams and mercury-containing vaccines.

6. Methylmercury is adversely affecting both humans and wildlife. This compound readily passes the placental barrier and the blood-brain barrier, and is a neurotoxicant, which may in particular cause adverse effects on the developing brain. Studies have shown that methylmercury in pregnant women's diets can have subtle, persistent adverse effects on children's development as observed at about the start of school age. Moreover, some studies suggest small increases in methylmercury exposure may cause adverse effects on the cardiovascular system. Many people (and wildlife) are currently exposed at levels that pose risks of these, and possibly other adverse effects.

7. Some populations are especially susceptible to mercury exposure, most notably the fetus, the newborn, and young children because of the sensitivity of the developing nervous system. Thus, parents,

pregnant women, and women who might become pregnant, should be particularly aware of the potential harm of methylmercury. Moderate consumption of fish (with low mercury levels) is not likely to result in exposures of concern. However, indigenous populations and others who consume higher amounts of contaminated fish or marine mammals, as well as workers who are exposed to mercury, such as in small-scale gold and silver mining, may be highly exposed to mercury and are therefore at risk.

8. Besides their importance to many native cultures, fish are an extremely valuable component of the human diet in many parts of the world, providing nutrients that are often not available in alternative food sources. Mercury is a major threat to this food supply. Likewise, contaminated fish can bring serious economic problems to communities and regions dependent on fisheries for their economic survival.

9. There are also particularly vulnerable ecosystems and wildlife populations. These include top predators in aquatic food webs (such as fish-eating birds and mammals), Arctic ecosystems, wetlands, tropical ecosystems and soil microbial communities.

Intervention Can be Successful

10. Mercury pollution has significant impacts at local, national, regional and global levels. These impacts can be addressed through a range of actions at each of these levels, targeting reductions in uses, releases and exposures. Numerous actions implemented in Europe, North America and elsewhere have successfully reduced uses and releases of mercury. However, inventories are still incomplete in these regions, and some releases are still significant. The extent of decreases in environmental levels and ecosystem improvements in response to decreased releases of mercury will vary considerably depending on local ecosystem characteristics and other factors, and in some cases may take several decades. However, an evaluation of mercury levels in Swedish lakes indicates that, by reducing releases, environmental levels of mercury, such as in freshwater fish, may be reduced significantly in specific locations within one to two decades.

WHY IS LOCAL/REGIONAL ACTION, BY ITSELF, NOT SUFFICIENT?

Global Cycling of Mercury Increases the Problem

11. As described above, the origins of atmospheric mercury deposition are local and regional as well as hemispherical or global. Besides local sources of mercury releases (such as waste incineration and coal combustion facilities), the general global background concentrations (global pool) contribute significantly to the mercury burden at most locations. Similarly, virtually any local source contributes to the global pool. Also, rivers and ocean currents are media for long-range mercury transport.

12. In some nations, local and regional mercury depositions have gradually increased contamination levels to the point that countermeasures have been enacted in recent decades to reduce emissions. However, due to long-range transport, even nations with minimal mercury releases, and other areas remote from industrial activity, may be adversely affected. For example, high mercury levels are observed in the Arctic, far from the sources of any significant releases.

Mercury Has an Impact on Global Fishing

13. Many fish species in international waters migrate to remote and diverse locations. Moreover, after harvest, commercial fish are commonly exported to various nations throughout the world, to locations far removed from place of origin. Therefore, mercury contamination of lakes, rivers, and especially oceans is truly a global issue, affecting fishing industries and fish consumers around the world.

Mercury May Be More Problematic to Less-Developed Regions

14. As awareness of mercury's adverse impacts has increased, the uses of mercury have been reduced significantly in many industrialised countries. Alternatives are commercially and competitively available for most uses. However, these reductions in use have had the effect of lowering demand relative to the supply of mercury, which has kept mercury prices low and encouraged ongoing (and in some cases, increased) use of mercury and outdated mercury technologies in less-developed regions or nations. As mer-

cury regulations and restrictions are less comprehensive or less well enforced in many less-developed regions, these trends have contributed to the concentration, in these areas, of a disproportionate burden of some of the health and environmental risks that accompany mercury.

Mercury is Subject to Significant International Use and Commerce

15. Despite improved awareness of risks, mercury continues to be used in a variety of products and processes all over the world. Elemental mercury metal is used in small-scale mining of gold and silver; chlor-alkali production; manometers for measurement and control; thermometers; electrical switches; fluorescent lamps; and dental amalgam fillings. Mercury compounds are used in batteries; biocides in the paper industry, pharmaceuticals; paints and on seed grain; and as laboratory reagents and industrial catalysts.

16. There is significant ongoing trade in mercury and mercury-containing products, some of which is illegal, uncontrolled and/or unregulated. The most significant global movement of mercury that remains poorly understood is the flow of mercury through international commerce. While overall quantities of mercury traded (and mined) have diminished in recent years, significant amounts are still transported. The unabated demand in many developing nations is a particular concern. Mercury available on the world market is supplied from a number of sources, including, among others:

- Mining of mercury (extracted from ores within the earth's crust) either as the main product or as a by-product of mining and refining other metals (gold, zinc) or minerals;
- Private and government stocks (mercury in chlor-alkali plants, government reserves);
- Recycled mercury recovered from spent products and industrial wastes.

17. Even under current regulations and restrictions, many of the uses and movements of mercury and mercury containing products are likely to eventually result in the release of mercury to the global environment. Meanwhile, large amounts of mercury that remain in mine tailings, landfills and sediments, as well as stockpiles, continue to present a threat of future release. Hence, actions to reduce, manage and address uses, stocks and trade may be useful at local, regional, national and international levels to prevent or minimize future releases.

HOW DOES MERCURY GET INTO HUMANS AND WILDLIFE?

18. Although local conditions may affect mercury exposure in certain populations, most people are primarily exposed to methylmercury through the diet (especially fish) and to elemental mercury vapours due to dental amalgams and occupational activities. The toxicity of methylmercury is described above. Elemental mercury vapour is also toxic to the nervous system and other organs. While methylmercury is of greatest concern for general populations, elevated exposures to elemental mercury are also of concern.

19. Elevated methylmercury levels have been measured in numerous freshwater and marine fish species throughout the world. The highest levels are found in large predatory fish and fish-consuming mammals. Exposure studies from diverse geographic areas indicate that a significant portion of humans and wildlife throughout the world are exposed to methylmercury at levels of concern, primarily due to consumption of contaminated fish.

20. 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, use in some traditional medicines and mercury in the home and working environment can result in substantial elevations of human exposure. Exposures also occur through the use of vaccines and some other pharmaceuticals containing mercury preservatives (such as Thimerosal/Thiomersal).

21. Elevated elemental mercury levels in the working environment have been reported in chlor-alkali plants, mercury mines, thermometer factories, refineries, dental clinics, and in mining and manufacturing of gold and silver extracted with mercury. The relative impacts from local pollution (such as former mining sites), occupational exposure and local traditions may vary considerably between nations and are known to be significant in some areas.

22. Numerous wildlife species that rely on fish as a large part of their diet can have elevated mercury levels that raise the risk of adverse effects. Animals with the highest mercury levels include otter, mink, raptors, osprey, and eagles, which are top predators in the aquatic food chain. For example, eggs of certain Canadian bird species have mercury levels that are a threat to reproduction. Moreover, mercury levels in Arctic ringed seals and beluga whales have increased by 2 to 4 times over the last 25 years in some areas of the Canadian Arctic and Greenland. In warmer waters, some predatory marine mammals are also at risk. In addition, recent evidence indicates that soils are adversely affected over large parts of Europe and potentially in many other locations. However, in some environments, even fairly heavy mercury loads have very little effect on organisms as either mercury is not efficiently bioaccumulated throughout the local food chain or the mercury is not easily methylated. In addition, the effects of watershed management practises in certain locations on methylmercury levels may be more significant than the effects of direct or diffuse mercury inputs.

WHAT ARE THE PRIMARY SOURCES OF MERCURY RELEASES?

23. The releases of mercury can be grouped in four categories:

- Natural sources - releases due to natural mobilisation of naturally occurring mercury from the Earth's crust, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of mercury impurities in raw materials such as fossil fuels – particularly coal, and to a lesser extent gas and oil – and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;
- Re-mobilisation of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles.

24. A large portion of the mercury present in the atmosphere today is the result of many years of anthropogenic emissions. The natural component of the total atmospheric burden is difficult to estimate, although available data suggest anthropogenic activities have increased levels of mercury in the atmosphere by roughly a factor of 3, average deposition rates by a factor of 1.5 to 3 and deposition near industrial areas by a factor of 2 to 10.

25. Highly contaminated industrial sites and abandoned mining operations continue to release mercury. Also, land, water and resource management activities such as forestry and agricultural practices and flooding can make mercury more bioavailable. Methylation and bioaccumulation are influenced by high levels of nutrients and organic matter in water bodies. In addition, frequent extreme weather events can contribute to release of mercury through flooding and soil erosion.

WHAT ARE THE ANTHROPOGENIC SOURCES?

26. With regard to anthropogenic releases, the relative importance of releases associated with intentional uses versus mobilisation of mercury impurities vary between nations and regions, particularly depending on: extent of substitution of intentional uses (products and processes); reliance on fossil fuels, particularly coal, for energy; extent of mining and mineral extraction industry; waste disposal practices; and state of implementation of pollution control technologies. In nations where there is mercury mining or use of mercury for small-scale gold or silver mining, these sources can be quite significant.

27. Some of the more important anthropogenic processes that mobilise mercury impurities include: coal-fired power and heat generation; cement production; and mining and other metallurgic activities involving the extraction and processing of mineral materials, such as production of iron and steel, zinc and gold. Some important sources of anthropogenic releases that occur from the intentional extraction and use of mercury include: mercury mining; small-scale gold and silver mining; chlor-alkali production; (breakage during) use of fluorescent lamps, auto headlamps, manometers, thermostats, thermometers, and

other instruments; dental amalgam fillings; manufacturing of products containing mercury; waste treatment and incineration of products containing mercury; landfills; and cremation.

HOW CAN RELEASES BE REDUCED?

28. Reducing or eliminating anthropogenic mercury releases will require controlling releases from mercury-contaminated raw materials and feedstocks as well as reducing or eliminating the use of mercury in products and processes. The specific methods for controlling these mercury releases vary widely, depending upon local circumstances, but fall generally under four groups:

- Reducing mercury mining and consumption of raw materials and products that generate releases;
- Substitution of products and processes containing or using mercury;
- Controlling mercury releases through end-of-pipe controls; and
- Mercury waste management.

29. The first two of these are "preventive" measures – preventing some uses or releases of mercury from occurring at all. The latter two are "control" measures, which reduce (or delay) some releases. Preventive measures for reducing consumption of raw materials and products that generate mercury releases are generally cost-effective, and among the most viable means of eliminating mercury releases. Also, substitution of products and processes without mercury is an important preventive action.

30. Controlling mercury releases through end-of-pipe techniques, such as exhaust gas filtering, may be especially appropriate to processes using raw materials with trace mercury contamination - fossil-fueled power plants, cement production, extraction and processing of primary raw materials such as zinc, gold and other metals, and processing of secondary raw materials such as steel scrap. Existing control technologies that reduce sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) for coal-fired boilers and incinerators, while not widely used in many countries, also yield some level of mercury control. Technology for additional mercury control is under development and demonstration, but is not yet commercially deployed. In the long run, integrated multi-pollutant (SO_2, NO_x, PM, and mercury) control technologies may be a cost-effective approach. However, end-of-pipe control technologies, while mitigating the problem of atmospheric mercury pollution, still result in mercury wastes that are potential sources of future emissions and should be disposed of or reused in an environmentally acceptable manner.

31. Mercury waste management has become more complex as more mercury is collected from a variety of sources, including gas filtering products, sludges from the chlor-alkali industry, ashes, and mineral residues, as well as used fluorescent tubes, batteries and other products that are often not recycled. The cost of acceptable disposal of mercury waste in some countries is such that many producers now investigate whether alternative non-mercury products exist. Proper management of mercury wastes is important to reduce releases to the environment, including those that occur due to spills (such as broken thermometers) or releases that occur over time due to leakage from certain uses (such as auto switches and dental amalgams) or releases through waste incineration and cremation. A well thought-out combination of prevention and control measures is necessary to optimize reductions in mercury releases.

32. Many nations have implemented actions to limit and prevent uses, releases and exposures, such as:

- Actions and regulations that control mercury releases into the environment;
- Product control actions and regulations for mercury-containing products;
- Environmental quality standards, specifying a maximum acceptable mercury concentration for different media such as drinking water, surface waters, air, soil and foodstuffs such as fish;
- Other standards, actions and programmes, such as regulations on mercury exposures in the workplace, reporting requirements, fish consumption advisories and consumer safety measures.

33. Although legislation is a key component of most national initiatives, other efforts exist to reduce mercury use such as developing and introducing safer alternatives and cleaner technology, the use of subsidies and incentives to encourage substitution efforts, voluntary agreements with industry, and awareness raising.

34. Because of mercury's long-range cycling and persistence in the environment, a number of countries have already initiated measures at regional, sub-regional and international levels to identify common reduction goals and ensure coordinated implementation among countries.

WHAT WOULD IMPROVE OUR UNDERSTANDING AND INTERNATIONAL COORDINATION?

35. Despite data gaps, sufficient understanding has been developed of mercury (including knowledge of its fate and transport, health and environmental impacts, and the role of human activity), based on extensive research over half a century, that international actions to address the global mercury problem should not be delayed. Nonetheless, further research and other activities would be useful to improve our understanding and coordination in a number of areas, including:

- Inventories of national uses, consumption and environmental releases;
- Information on transport, transformation, cycling, and fate of mercury in various compartments;
- Assessment and monitoring of mercury levels in various media (such as air and air deposition) and biota (such as fish), and associated impacts on humans and wildlife, including impacts from cumulative exposures to different forms of mercury;
- Data and evaluation tools for human and ecological risk assessments;
- Additional measures to prevent and reduce releases from various sources;
- Collaboration among nations dealing with the spectrum of scientific and technical issues, including mercury waste management and remediation; and
- Information on the global commerce and trade of mercury and mercury-containing materials.

Summary of the report

CHAPTER 1 - Introduction

36. This report responds to the request of the Governing Council (GC) of the United Nations Environment Programme (UNEP), through GC decision 21/5, that UNEP undertake a global assessment of mercury and mercury compounds, in cooperation with other members of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), to be presented to the Governing Council at its 22nd session in 2003. The assessment would include contributions from Governments, intergovernmental and non-governmental organizations and the private sector, and cover a number of specific elements defined in the GC decision. These elements are covered as far as possible in the different chapters of the report.

37. As part of the implementation of GC decision 21/5, UNEP established a Global Mercury Assessment Working Group to assist in the drafting and finalization of this report, first through a comment round by mail, then through a meeting of the Working Group, which took place 9-13 September 2002 in Geneva, Switzerland. The Working Group was open-ended and consisted of members nominated by Governments, intergovernmental organizations and non-governmental organizations.

38. This report will be forwarded to the Governing Council for consideration at its 22nd session in February 2003. By having initiated the development of this assessment report, the Governing Council will have a better basis for considering if any international action on mercury is called for in order to promote environmentally sound management of mercury and its compounds. The report will contribute to increased awareness and understanding among decision makers of the major issues related to mercury and its compounds, thereby facilitating the debate on the issue at the next session of the Governing Council.

CHAPTER 2 – Chemistry

39. Mercury occurs naturally in the environment and exists in a large number of forms. Like lead or cadmium, mercury is a constituent element of the earth, a heavy metal. In pure form, it is known alternatively as "elemental" or "metallic" mercury (also expressed as Hg(0) or Hg^0). Mercury is rarely found in nature as the pure, liquid metal, but rather within compounds and inorganic salts. Mercury can be bound to other compounds as monovalent or divalent mercury (also expressed as Hg(I) and Hg(II) or Hg^{2+}, respectively). Many inorganic and organic compounds of mercury can be formed from Hg(II).

40. Elemental mercury is a shiny, silver-white metal that is a liquid at room temperature and is traditionally used in thermometers and some electrical switches. If not enclosed, at room temperature some of the metallic mercury will evaporate and form mercury vapours. Mercury vapours are colourless and odourless. The higher the temperature, the more vapours will be released from liquid metallic mercury. Some people who have breathed mercury vapours report a metallic taste in their mouths.

41. Mercury is mined as mercuric sulphide (cinnabar ore). Through history, deposits of cinnabar have been the source ores for commercial mining of metallic mercury. The metallic form is refined from mercuric sulphide ore by heating the ore to temperatures above 540 ° C. This vaporises the mercury in the ore, and the vapours are then captured and cooled to form the liquid metal mercury.

42. Inorganic mercuric compounds include mercuric sulphide (HgS), mercuric oxide (HgO) and mercuric chloride ($HgCl_2$). These mercury compounds are also called mercury salts. Most inorganic mercury compounds are white powders or crystals, except for mercuric sulphide, which is red and turns black after exposure to light. Some mercury salts (such as $HgCl_2$) are sufficiently volatile to exist as an atmospheric gas. However, the water solubility and chemical reactivity of these inorganic (or divalent) mercury gases lead to much more rapid deposition from the atmosphere than for elemental mercury. This results in sig-

nificantly shorter atmospheric lifetimes for these divalent mercury gases than for the elemental mercury gas.

43. When mercury combines with carbon, the compounds formed are called "organic" mercury compounds or organomercurials. There is a potentially large number of organic mercury compounds (such as dimethylmercury, phenylmercury, ethylmercury and methylmercury); however, by far the most common organic mercury compound in the environment is methylmercury. Like the inorganic mercury compounds, both methylmercury and phenylmercury exist as "salts" (for example, methylmercuric chloride or phenylmercuric acetate). When pure, most forms of methylmercury and phenylmercury are white crystalline solids. Dimethylmercury, however, is a colourless liquid.

44. Several forms of mercury occur naturally in the environment. The most common natural forms of mercury found in the environment are metallic mercury, mercuric sulphide, mercuric chloride, and methylmercury. Some micro-organisms and natural processes can change the mercury in the environment from one form to another.

45. Elemental mercury in the atmosphere can undergo transformation into inorganic mercury forms, providing a significant pathway for deposition of emitted elemental mercury.

46. The most common organic mercury compound that micro-organisms and natural processes generate from other forms is methylmercury. Methylmercury is of particular concern because it can build up (bioaccumulate and biomagnify) in many edible freshwater and saltwater fish and marine mammals to levels that are many thousands of times greater than levels in the surrounding water.

47. Methylmercury can be formed in the environment by microbial metabolism (biotic processes), such as by certain bacteria, and by chemical processes that do not involve living organisms (abiotic processes). Although, it is generally believed that its formation in nature is predominantly due to biotic processes. Significant direct anthropogenic (or human generated) sources of methylmercury are currently not known, although historic sources have existed. Indirectly, however, anthropogenic releases contribute to the methylmercury levels found in nature because of the transformation of other forms. Examples of direct release of organic mercury compounds are the Minamata methylmercury-poisoning event that occurred in the 1950's where organic mercury by-products of industrial-scale acetaldehyde production were discharged in the local bay, and the Iraqi poisoning events where wheat treated with a seed dressing containing organic mercury compounds were used for bread. Also, new research has shown that methylmercury can be released directly from municipal waste landfills (Lindberg *et al.*, 2001) and sewage treatment plants (Sommar *et al.*, 1999), but the general significance of this source is still uncertain.

48. Being an element, mercury cannot be broken down or degraded into harmless substances. Mercury may change between different states and species in its cycle, but its simplest form is elemental mercury, which itself is harmful to humans and the environment. Once mercury has been liberated from either ores or from fossil fuel and mineral deposits hidden in the earth's crust and released into the biosphere, it can be highly mobile, cycling between the earth's surface and the atmosphere. The earth's surface soils, water bodies and bottom sediments are thought to be the primary biospheric sinks for mercury.

Mercury exists in the following main states under natural conditions

- As metallic vapour and liquid/elemental mercury;
- Bound in mercury containing minerals (solid);
- As ions in solution or bound in ionic compounds (inorganic and organic salts);
- As soluble ion complexes;
- As gaseous or dissolved non-ionic organic compounds;
- Bound to inorganic or organic particles/matter by ionic, electrophilic or lipophilic adsorption.

Significance of mercury speciation

49. The different forms mercury exists in (such as elemental mercury vapour, methylmercury or mercuric chloride) are commonly designated "species". As mentioned above, the main groups of mercury species are elemental mercury, inorganic and organic mercury forms. Speciation is the term commonly used to represent the distribution of a quantity of mercury among various species.

50. Speciation plays an important part in the toxicity and exposure of mercury to living organisms. Among other things, the species influence:

- The physical availability for exposure - if mercury is tightly bound to in-absorbable material, it cannot be readily taken up (e.g. into the blood stream of the organism);
- The internal transport inside the organism to the tissue on which it has toxic effects - for example the crossing of the intestinal membrane or the blood-brain barrier;
- Its toxicity (partly due to the above mentioned);
- Its accumulation, bio-modification, detoxification in – and excretion from – the tissues;
- Its bio-magnification on its way up the trophic levels of the food chain (an important feature particularly for methylmercury).

51. Speciation also influences the transport of mercury within and between environmental compartments including the atmosphere and oceans, among others. For example, the speciation is a determining factor for how far from the source mercury emitted to air is transported. Mercury adsorbed on particles and ionic (e.g. divalent) mercury compounds will fall on land and water mainly in the vicinity of the sources (local to regional distances), while elemental mercury vapour is transported on a hemispherical/global scale making mercury emissions a global concern. Another example is the so-called "polar sunrise mercury depletion incidence", where the transformation of elemental mercury to divalent mercury is influenced by increased solar activity and the presence of ice crystals, resulting in a substantial increase in mercury deposition during a three month period (approximately March to June).

52. Moreover, speciation is very important for the controllability of mercury emissions to air. For example, emissions of inorganic mercuric compounds (such as mercuric chloride) are captured reasonably well by some control devices (such as wet-scrubbers), while capture of elemental mercury tends to be low for most emission control devices.

CHAPTER 3 – Toxicology

53. The toxicity of mercury depends on its chemical form, and thus symptoms and signs are rather different in exposure to elemental mercury, inorganic mercury compounds, or organic mercury compounds (notably alkylmercury compounds such as methylmercury and ethylmercury salts, and dimethylmercury). The sources of exposure are also markedly different for the different forms of mercury. For alkylmercury compounds, among which methylmercury is by far the most important, the major source of exposure is diet, especially fish and other seafood. For elemental mercury vapour, the most important source for the general population is dental amalgam, but exposure at work may in some situations exceed this by many times. For inorganic mercury compounds, diet is the most important source for the majority of people. However, for some segments of populations, use of skin-lightening creams and soaps that contain mercury, and use of mercury for cultural/ritualistic purposes or in traditional medicine, can also result in substantial exposures to inorganic or elemental mercury.

54. While it is fully recognised that mercury and its compounds are highly toxic substances for which potential impacts should be considered carefully, there is ongoing debate on how toxic these substances, especially methylmercury, are. New findings during the last decade indicate that toxic effects may be taking place at lower concentrations than previously thought, and potentially larger parts of the global population may be affected. As the mechanisms of subtle toxic effects – and proving whether such effects are taking place – are extremely complex issues, a complete understanding has so far not been reached on this very important question.

Methylmercury

55. Of the organic mercury compounds, methylmercury occupies a special position in that large populations are exposed to it, and its toxicity is better characterized than that of other organic mercury compounds. Within the group of organic mercury compounds, alkylmercury compounds (especially ethylmercury and methylmercury) are thought to be rather similar as to toxicity (and also historical use as pesticides), while other organic mercury compounds, such as phenylmercury, resemble more inorganic mercury in their toxicity.

56. Methylmercury is a well-documented neurotoxicant, which may in particular cause adverse effects on the developing brain. Moreover, this compound readily passes both the placental barrier and the blood-brain barrier, therefore, exposures during pregnancy are of highest concern. Also, some studies suggest that even small increases in methylmercury exposures may cause adverse effects on the cardiovascular system, thereby leading to increased mortality. Given the importance of cardiovascular diseases worldwide, these findings, although yet to be confirmed, suggest that methylmercury exposures need close attention and additional follow-up. Moreover, methylmercury compounds are considered possibly carcinogenic to humans (group 2B) according to the International Agency for Research on Cancer (IARC, 1993), based on their overall evaluation.

Elemental mercury and inorganic mercury compounds

57. The main route of exposure for elemental mercury is by inhalation of the vapours. About 80 percent of inhaled vapours are absorbed by the lung tissues. This vapour also easily penetrates the blood-brain barrier and is a well-documented neurotoxicant. Intestinal absorption of elemental mercury is low. Elemental mercury can be oxidized in body tissues to the inorganic divalent form.

58. Neurological and behavioural disorders in humans have been observed following inhalation of elemental mercury vapour. Specific symptoms include tremors, emotional lability, insomnia, memory loss, neuromuscular changes, and headaches. In addition, there are effects on the kidney and thyroid. High exposures have also resulted in death. With regard to carcinogenicity, the overall evaluation, according to IARC (1993), is that metallic mercury and inorganic mercury compounds are not classifiable as to carcinogenicity to humans (group 3). A critical effect on which risk assessment could be based is therefore the neurotoxic effects, for example the induction of tremor. The effects on the kidneys (the renal tubule) should also be considered; they are the key endpoint in exposure to inorganic mercury compounds. The effect may well be reversible, but as the exposure to the general population tends to be continuous, the effect may still be relevant.

Summary of effect levels

59. To put the level of exposures for methylmercury in perspective, for the most widely accepted non-lethal adverse effect (neurodevelopmental effects), the United States (US) National Research Council (NRC, 2000) has estimated the benchmark dose (BMD) to be 58 micrograms per litre (µg/l) total mercury in cord blood (or 10 micrograms per gram (µg/g) total mercury in maternal hair) using data from the Faroe Islands study of human mercury exposures (Grandjean et al., 1997). This BMD level is the lower 95% confidence limit for the exposure level that causes a doubling of a 5% prevalence of abnormal neurological performance (developmental delays in attention, verbal memory and language) in children exposed in-utero in the Faroe Islands study. These are the tissue levels estimated to result from an average daily intake of about 1 µg methylmercury per kg body weight per day (1 µg/kg body weight per day).

60. Other adverse effects have been seen in humans with less reliability or at much higher exposures. For methylmercury, effects have been seen on the adult nervous system, on cardiovascular disease, on cancer incidence and on genotoxicity. Also, effects have been reported on heart rate variability and blood pressure in 7 year-old children exposed prenatally, and on cardiovascular mortality in adults. For elemental mercury and inorganic mercury compounds, effects have been seen on: the excretion of low molecular weight proteins; on enzymes associated with thyroid function; on spontaneous abortion rates; genotoxicity; respiratory system; gastrointestinal (digestion) system; liver; immune system; and the skin.

Dietary considerations

61. Fish are an extremely important component of the human diet in many parts of the world and provide nutrients (such as protein, omega-3 fatty acids and others) that are not easily replaced. Mercury is a major threat to this food supply. Certainly, fish with low methylmercury levels are intrinsically more healthful for consumers than fish with higher levels of methylmercury, if all other factors are equal.

62. There is limited laboratory evidence suggesting that several dietary components might reduce (e.g. selenium, vitamin E, omega-3 fatty acids) or enhance (e.g. alcohol) mercury's toxicity for some end-points. However, conclusions cannot be drawn from these data at this time.

CHAPTER 4 - Current mercury exposure and risk evaluations for human health

63. 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, as well as in mining and manufacturing of gold extracted with mercury. Additional exposures result from the use of Thimerosal/Thiomersal (ethylmercury thiosalicylate) as a preservative in some vaccines and other pharmaceuticals. 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.

64. The chapter gives 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 United States of America (USA), the Arctic, Japan, China, Indonesia, Papua New Guinea, Thailand, Republic of Korea, Philippines, the Amazonas and French Guyana. 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). As shown in the chapter, data indicate exposures are generally higher in Greenland, Japan and some other areas as compared to the USA.

65. 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.

66. 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 the chapter. The mercury concentrations in various fish species are generally from about 0.05 to 1.4 milligrams of mercury per kilogram of fish tissue (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 (for fish, and sometimes marine mammals) in a number of countries, 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.

CHAPTER 5 – Impacts of mercury on the environment

Build-up of mercury in food webs

67. A very important factor in the impacts of mercury to the environment is its ability to build up in organisms and up along the food chain. Although all forms of mercury can accumulate to some degree, methylmercury is absorbed and accumulates to a greater extent than other forms. Inorganic mercury can also be absorbed, but is generally taken up at a slower rate and with lower efficiency than is methylmercury. The biomagnification of methylmercury has a most significant influence on the impact on animals and humans. Fish appear to bind methylmercury strongly, nearly 100 percent of mercury that bioaccumulates in predator fish is methylmercury. Most of the methylmercury in fish tissue is covalently bound to protein sulfhydryl groups. This binding results in a long half-life for elimination (about two years). As a consequence, there is a selective enrichment of methylmercury (relative to inorganic mercury) as one moves from one trophic level to the next higher trophic level.

Bioaccumulation and biomagnification

The term **bioaccumulation** refers to the net accumulation over time of metals within an organism from both biotic (other organisms) and abiotic (soil, air, and water) sources.
The term **biomagnification** refers to the progressive build up of some heavy metals (and some other persistent substances) by successive trophic levels – meaning that it relates to the concentration ratio in a tissue of a predator organism as compared to that in its prey (AMAP, 1998).

68. In contrast to other mercury compounds the elimination of methylmercury from fish is very slow. Given steady environmental concentrations, mercury concentrations in individuals of a given fish species tend to increase with age as a result of the slow elimination of methylmercury and increased intake due to changes in trophic position that often occur as fish grow to larger sizes (i.e., the increased fish-eating and the consumption of larger prey items). Therefore, older fish typically have higher mercury concentrations in the tissues than younger fish of the same species.

69. The mercury concentrations are lowest in the smaller, non-predatory fish and can increase many-fold on the way up the food chain. Apart from the concentration in food, other factors affect the bioaccumulation of mercury. Of most importance are the rates of methylation and demethylation by mercury methylating bacteria (e.g., sulphate reducers). When all of these factors are combined, the net methylation rate can strongly influence the amount of methylmercury that is produced and available for accumulation and retention by aquatic organisms. As described in chapter 2, several parameters in the aquatic environment influence the methylation of mercury and thereby its biomagnification. While much is generally known about mercury bioaccumulation and biomagnification, the process is extremely complex and involves complicated biogeochemical cycling and ecological interactions. As a result, although accumulation/magnification can be observed, the extent of mercury biomagnification in fish is not easily predicted across different sites.

70. At the top levels of the aquatic food web are fish-eating species, such as humans, seabirds, seals and otters. The larger wildlife species (such as eagles, seals) prey on fish that are also predators, such as trout and salmon, whereas smaller fish-eating wildlife (such as kingfishers) tend to feed on the smaller forage fish. In a study of fur-bearing animals in Wisconsin, the species with the highest tissue levels of

mercury were otter and mink, which are top mammalian predators in the aquatic food chain. Top avian predators of aquatic food chains include raptors such as the osprey and bald eagle. Thus, mercury is transferred and accumulated through several food web levels (US EPA, 1997). Aquatic food webs tend to have more levels than terrestrial webs, where wildlife predators rarely feed on each other, and therefore the aquatic biomagnification typically reaches higher values.

Mercury compounds toxic to wildlife

71. Methylmercury is a central nervous system toxin, and the kidneys are the organs most vulnerable to damage from inorganic mercury. Severe neurological effects were already seen in animals in the notorious case from Minamata, Japan, prior to the recognition of the human poisonings, where birds experienced severe difficulty in flying, and exhibited other grossly abnormal behaviour. Significant effects on reproduction are also attributed to mercury, and methylmercury poses a particular risk to the developing fetus since it readily crosses the placental barrier and can damage the developing nervous system.

72. In birds, adverse effects of mercury on reproduction can occur at egg concentrations as low as 0.05 to 2.0 mg/kg (wet weight). Eggs of certain Canadian species are already in this range, and concentrations in the eggs of several other Canadian species continue to increase and are approaching these levels.

73. The levels of mercury in Arctic ringed seals and beluga whales have increased by 2 to 4 times over the last 25 years in some areas of the Canadian Arctic and Greenland. In warmer waters as well, predatory marine mammals may also be at risk. In a study of Hong Kong’s population of hump-backed dolphins, mercury was identified as a particular health hazard, more than other heavy metals.

Vulnerable ecosystems

74. Recent evidence suggests that mercury is responsible for a reduction of micro-biological activity vital to the terrestrial food chain in soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics. Preliminary critical limits to prevent ecological effects due to mercury in organic soils have been set at 0.07-0.3 mg/kg for the total mercury content in soil.

75. On the global scale, the Arctic region has been in focus recently because of the long-range transport of mercury. However, impacts from mercury are by no means restricted to the Arctic region of the world. The same food web characteristics - and a similar dependence on a mercury contaminated food source - are found in specific ecosystems and human communities in many countries of the world, particularly in places where a fish diet is predominant.

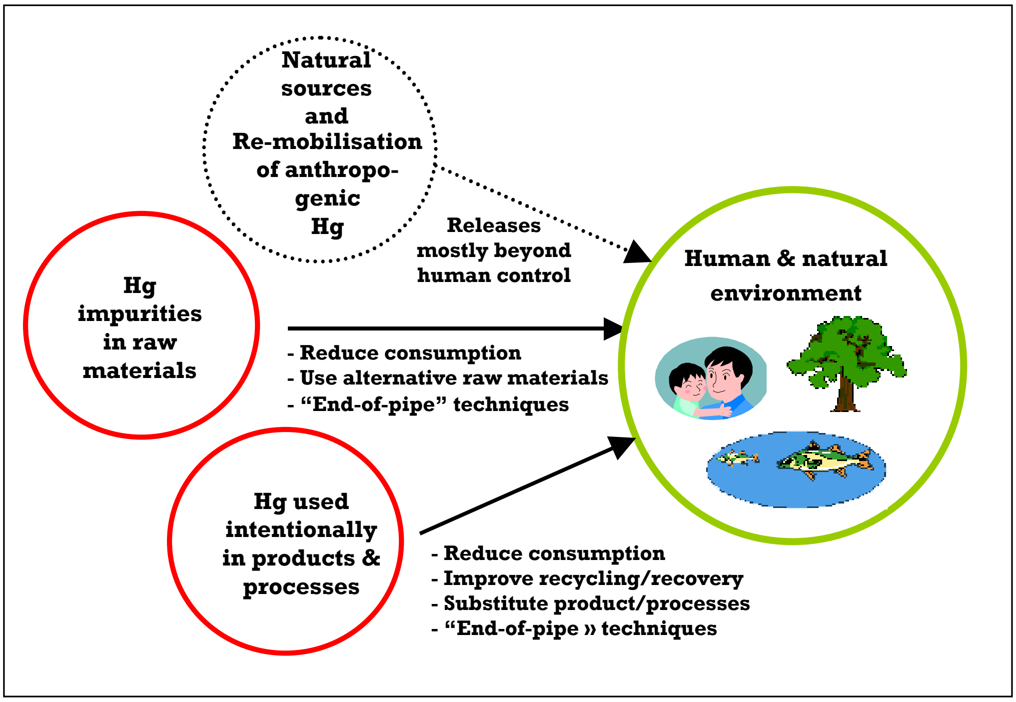
76. Rising water levels associated with global climate change may also have implications for the methylation of mercury and its accumulation in fish. For example, there are indications of increased formation of methylmercury in small, warm lakes and in many newly flooded areas.

CHAPTER 6 – Sources and cycling of mercury to the global environment

77. The releases of mercury to the biosphere can be grouped in four categories:

- Natural sources - releases due to natural mobilisation of naturally occurring mercury from the Earth's crust, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of mercury impurities in raw materials such as fossil fuels – particularly coal, and to a lesser extent gas and oil – and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;
- Re-mobilisation of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles.

78. The figure below shows these release categories with main types of possible control mechanisms.



79. The recipients of mercury releases to the environment include the atmosphere, water environments (aquatic) and soil environments (terrestrial). There are continuing interactions – fluxes of mercury – between these compartments. The speciation – the chemical form – of the released mercury varies depending on the source types and other factors. This also influences the impacts on human health and environment as different mercury species have different toxicity.

80. Given the understanding of the global mercury cycle, current releases add to the global pool of mercury in the biosphere – mercury that is continuously mobilised, deposited on land and water surfaces, and re-mobilised. Being an element, mercury is persistent – it cannot be broken down to less toxic substances in the environment. The only long-term sinks for removal of mercury from the biosphere are deep-sea sediments and, to a certain extent, controlled landfills, in cases where the mercury is physio-chemically immobilised and remains undisturbed by anthropogenic or natural activity (climatic and geological). This also implies that even as the anthropogenic releases of mercury are gradually eliminated, decreases in some mercury concentrations – and related environmental improvements – will occur only slowly, most likely over several decades or longer. However, improvements may occur more quickly in specific locations or regions that are largely impacted by local or regional sources.

Local releases – global effects

81. The origins of atmospheric mercury deposition (flow of mercury from air to land and oceans) are local and regional as well as hemispherical or global. Several large studies have supported the conclusion that, in addition to local sources (such as chlor-alkali production, coal combustion and waste incineration facilities), the general background concentration of mercury in the global atmosphere contributes significantly to the mercury burden at most locations. Similarly, virtually any local source contributes to the background concentration – the global mercury pool in the biosphere - much of which represents anthropogenic releases accumulated over the decades. Also, the ocean currents are media for long-range mercury transport, and the oceans are important dynamic sinks of mercury in the global cycle.

82. The majority of atmospheric anthropogenic emissions are released as gaseous elemental mercury. This is capable of being transported over very long distances with the air masses. The remaining part of air emissions are in the form of gaseous divalent compounds (such as $HgCl_2$) or bound to particles present in the emission gas. These species have a shorter atmospheric lifetime than elemental vapour and will deposit via wet or dry processes within roughly 100 to 1000 kilometers. However, significant conversion

between mercury species may occur during atmospheric transport, which will affect the transport distance.

83. The atmospheric residence time of elemental mercury is in the range of months to roughly one year. This makes transport on a hemispherical scale possible and emissions in any continent can thus contribute to the deposition in other continents. For example, based on modelling of the intercontinental mercury transport performed by EMEP/MSC-E (Travnikov and Ryaboshapko, 2002), up to 50 percent of anthropogenic mercury deposited to North America is from external sources. Similarly, contributions of external sources to anthropogenic mercury depositions to Europe and Asia were estimated to be about 20 percent and 15 percent, respectively.

84. Furthermore, as mentioned, mercury is also capable of re-emissions from water and soil surfaces. This process greatly enhances the overall residence time of mercury in the environment. Recent findings by Lindberg *et al*. (2001) indicate re-emission rates of approximately 20 percent over a two-year period, based on stable mercury isotope measurements in north-western Ontario, Canada.

Anthropogenic sources of mercury releases

85. A large portion of the mercury present in the atmosphere today is the result of many years of releases due to anthropogenic activities. The natural component of the total atmospheric burden is difficult to estimate, although a recent study (Munthe *et al.*, 2001) has suggested that anthropogenic activities have increased the overall levels of mercury in the atmosphere by roughly a factor of 3.

86. While there are some natural emissions of mercury from the earth's crust, anthropogenic sources are the major contributors to releases of mercury to the atmosphere, water and soil.

Examples of important sources of anthropogenic releases of mercury

Releases from mobilisation of mercury impurities:

- Coal-fired power and heat production (largest single source to atmospheric emissions)
- Energy production from other fossil carbon fuels
- Cement production (mercury in lime)
- Mining and other metallurgic activities involving the extraction and processing of virgin and recycled mineral materials, for example production of:
  - iron and steel
  - ferromanganese
  - zinc
  - gold
  - other non-ferrous metals

Releases from intentional extraction and use of mercury:

- Mercury mining
- Small-scale gold and silver mining (amalgamation process)
- Chlor-alkali production
- Use of fluorescent lamps, various instruments and dental amalgam fillings.
- Manufacturing of products containing mercury, for example:
  - thermometers
  - manometers and other instruments
  - electrical and electronic switches

Releases from waste treatment, cremation etc. (originating from both impurities and intentional uses of mercury):

- Waste incineration (municipal, medical and hazardous wastes)
- Landfills
- Cremation
- Cemeteries (release to soil)

87. There are significant uncertainties in the available release inventories, not only by source, but also by country. The best available estimates of mercury emissions to air from various significant sources are shown in the table below.

*Table Estimates of global atmospheric releases of mercury from a number of major anthropogenic sources in 1995 (metric tons/year). Releases to other media are not accounted for here. *1.*

Continent	**Stationary combustion**	**Non-ferrous metal production *5**	**Pig iron and steel production**	**Cement production**	**Waste disposal *2**	**Artisanal gold mining *4**	**Sum, quantified sources *3**
Europe	186	15	10	26	12		250
Africa	197	7.9	0.5	5.2			210
Asia	**860**	**87**	**12**	**82**	33		1070
North America	105	25	4.6	13	**66**		210
South America	27	25	1.4	5.5			60
Australia and Oceania	100	4.4	0.3	0.8	0.1		100
Sum, quantified sources, 1995 *3,4	1470	170	30	130	110	300	1900 +300
Based on references:	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Lacerda (1997)	

1 Note that releases to aquatic and terrestrial environments - as well as atmospheric releases from a number of other sources - are not included in the table, because no recent global estimates have been made. See chapter 6 for description of this issue.

2 Considered underestimated by authors of the inventory, see notes to table 6.10.

3 Represents total of the sources mentioned in this table, not all known sources. Sums are rounded and may therefore not sum up precisely.

4 Estimated emissions from artisanal gold mining refer to late 1980's/early 1990's situation. A newer reference (MMSD, 2002) indicates that mercury consumption for artisanal gold mining - and thereby most likely also mercury releases - may be even higher than presented here.

5 Production of non-ferrous metals releasing mercury, including mercury, zinc, gold, lead, copper, nickel.

88. The emissions from stationary combustion of fossil fuels (especially coal) and incineration of waste materials accounts for approximately 70 percent of the total quantified atmospheric emissions from major anthropogenic sources. As combustion of fossil fuels is increasing in order to meet the growing energy demands of both developing and developed nations, mercury emissions can be expected to increase accordingly in the absence of the deployment of control technologies or the use of alternative energy sources. Control technologies have been developed for coal combustion plants and waste incinerators with the primary intention of addressing acidifying substances (especially SO_2 and NO_x), and particulate matter (PM). Such existing technologies may provide some level of mercury control, but when viewed at the global level, currently these controls result in only a small reduction of mercury from these sources. Many control technologies are significantly less effective at reducing emissions of elemental mercury compared to other forms. Optimised technologies for mercury control are being developed and demonstrated, but are not yet commercially deployed.

89. Available global estimates of atmospheric emissions from waste incineration, as well as other releases originating from intentional uses of mercury in processes and products, are deemed underestimated, and to some degree incomplete. However, recorded virgin mercury production has been decreasing from about 6000 to about 2000 metric tons per year during the last two decades, and consequently, related releases from mining and usage of mercury may also be declining.

90. Anthropogenic emissions from a number of major sources have decreased during the last decade in North America and Europe due to reduction efforts. Also, total anthropogenic emissions to air have been declining in some developed countries in the last decade. For example, Canadian emissions were reduced from about 33 metric tons to 6 metric tons between 1990 and 2000.

Natural sources of mercury releases

91. Natural sources include volcanoes, evaporation from soil and water surfaces, degradation of minerals and forest fires. The natural mercury emissions are beyond our control, and must be considered part of our local and global living environment. It is necessary to keep this source in mind, however, as it does contribute to the environmental mercury levels. In some areas of the world, the mercury concentrations in the Earth's crust are naturally elevated, and contribute to elevated local and regional mercury concentrations in those areas.

92. Today's emissions of mercury from soil and water surfaces are composed of both natural sources and re-emission of previous deposition of mercury from both anthropogenic and natural sources. This makes it very difficult to determine the actual natural mercury emissions.

93. Published estimates of natural versus anthropogenic mercury emissions show significant variation, although more recent efforts have emphasized the importance of human contributions. Attempts to directly measure natural emissions are ongoing. Nonetheless, available information indicates that natural sources account for less than 50 percent of the total releases.

94. On average around the globe, there are indications that anthropogenic emissions of mercury have resulted in deposition rates today that are 1.5 to 3 times higher than those during pre-industrial times. In and around industrial areas the deposition rates have increased by 2 to 10 times during the last 200 years.

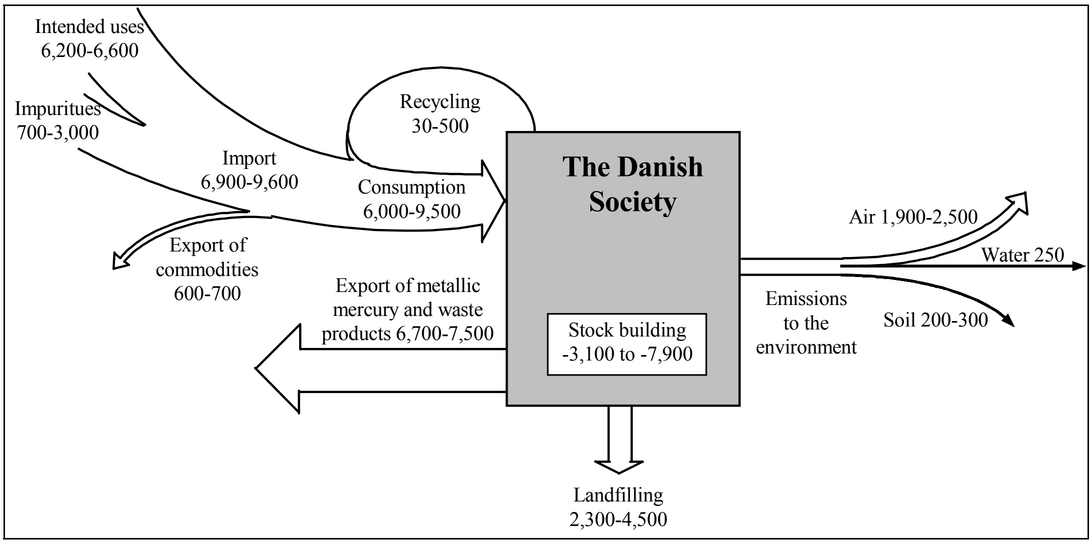
Contributions from intentional uses versus impurities in high volume materials

95. Regarding anthropogenic releases, the relative importance of intentional uses versus mobilisation of mercury impurities varies between countries and regions, particularly depending on:

- State of substitution of intentional uses (products and processes);
- Reliance on fossil fuels for energy production, particularly coal, and the presence of controls for other pollutants, which also reduce mercury emissions;
- Extent of mining and mineral extraction industry;
- Waste disposal pattern – incineration/landfilling;
- State of implementation of release control technologies in power production, waste incineration and various industrial processes.

96. For a number of countries, estimated contributions of intentional uses vary between 10 and 80 percent of the total domestic emissions to air, depending on the influence of the factors listed above. Rough estimates of distribution by main anthropogenic source types in each of these countries are shown in the chapter.

97. As an illustration, the figure below shows the overall turnover of mercury in the Danish society in 1992/93 in kilograms mercury/year (based on Maag *et al.*, 1996). (Note that inputs and outputs in the figure do not balance because outputs reflect higher inputs from previous years. Net change in stocks was negative.)



98. Denmark is a quite small country with relatively accurate monitoring of the flows of products and waste in the economy and the environment. Therefore, it has been possible to perform rather detailed balances, so-called substance flow assessments for mercury, which provide useful information on the contributions from different sectors to the total mercury burden in society and the environment. As shown in the figure, the majority of the input – more than two thirds – originated from intentional uses (chlor-alkali production and products), and the contributions from intentional uses to releases to air in 1992/93 could roughly be estimated at 50-80 percent of the total releases to air from Denmark. It should be noted that primary mineral extraction and processing is not as large a sector in Denmark, as in many other countries.

99. Examples of national distributions of anthropogenic mercury releases from different individual source types are given in the chapter. In countries where mercury mining or intentional use of mercury for small-scale gold mining is taking place, these sources can be significant.

CHAPTER 7 – Current production and use of mercury

Origin of mercury

100. Mercury is a natural component of the earth, with an average abundance of approximately 0.05 mg/kg in the earth's crust, with significant local variations. Mercury ores that are mined generally contain about one percent mercury, although the strata mined in Spain typically contain up to 12-14 percent mercury. While about 25 principal mercury minerals are known, virtually the only deposits that have been harvested for the extraction of mercury are cinnabar. Mercury is also present at very low levels throughout the biosphere. Its absorption by plants may account for the presence of mercury within fossil fuels like coal, oil, and gas, since these fuels are conventionally thought to be formed from geologic transformation of organic residues.

Sources of mercury to the market

101. The mercury available on the world market is supplied from a number of different sources, including (not listed in order of importance):

- Mine production of primary mercury (meaning extracted from ores within the earth's crust):
  - either as the main product of the mining activity,
  - or as by-product of mining or refining of other metals (such as zinc, gold, silver) or minerals;
- Recovered primary mercury from refining of natural gas (actually a by-product, when marketed, however, is not marketed in all countries);
- Reprocessing or secondary mining of historic mine tailings containing mercury;
- Recycled mercury recovered from spent products and waste from industrial production processes. Large amounts ("reservoirs") of mercury are "stored" in society within products still in use and "on the users' shelves";

- Mercury from government reserve stocks, or inventories;
- Private stocks (such as mercury in use in chlor-alkali and other industries), some of which may later be returned to the market.

102. The mining and other mineral extraction of primary mercury constitute the human mobilisation of mercury for intentional use in products and processes. Recycled mercury and mercury from stocks can be regarded as an anthropogenic re-mobilisation of mercury previously extracted from the Earth.

Continued mining of primary mercury

103. Despite a decline in global mercury consumption (global demand is less than half of 1980 levels), supply from competing sources and low prices, production of mercury from mining is still occurring in a number of countries. Spain, China, Kyrgyzstan and Algeria have dominated this activity in recent years, and several of the mines are state-owned. The table below gives information on recorded global primary production of mercury since 1981. There are also reports of small-scale, artisanal mining of mercury in China, Russia (Siberia), Outer Mongolia, Peru, and Mexico. It is likely that this production serves robust local demand for mercury, often for artisanal mining of gold – whether legal or illegal. Such mercury production would require both accessible mercury ores and low-cost labor in order for it to occur despite low-priced mercury available in the global commodity market.

Period	**1981-1985**	**1986-1989**	**1990-1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Recorded annual, global primary production (in metric tons)	5500-7100	4900-6700	3300-6100	2600-2800	2500-2900	2000-2800	2100-2200	1800

Sources: See section 7.2.1.

Large supplies of recycled mercury may be marketed

104. Large quantities of mercury have come onto the market as a result of ongoing substitution and closing of mercury-based chlor-alkali production in Europe and other regions. Market analysis indicates that 700 - 900 metric tons per year of recycled mercury (corresponding to about 30 percent of the recorded primary production) has been marketed globally since the mid-1990's, of which the majority originated from chlor-alkali production facilities. However, to the extent there remains a legitimate demand for mercury, the re-use and recycling of mercury replaces the mining and smelting of virgin mercury, which would involve additional releases and would result in mobilising new mercury into the market and the environment.

105. The preference for reuse and recycling of mercury over mining - especially in the context of large mercury inventories coming onto the market - is complicated by the generally accepted economic rule that an **excess** supply of mercury drives the market price lower, which in turn encourages additional use or waste of mercury. For this reason, certain precautions are being taken, as described below.

106. Within the current decade and beyond, vast supplies of mercury will become available from conversion or shutdown of chlor-alkali facilities using the mercury process, as many European countries press for a phase-out of this process before 2010. From the European Union alone, this may introduce up to 13,000 metric tons of additional mercury to the market (equal to some 6-12 years of primary mercury production). In response to this potential glut of mercury, Euro Chlor, which represents the European chlor-alkali industry, has signed a contractual agreement with Miñas de Almadén in Spain. The agreement provides that Miñas de Almadén will buy the surplus mercury from the West-European chlor-alkali plants and put it on the market in place of mercury Almadén would otherwise have mined. All EU members of Euro Chlor have agreed to sell their surplus mercury to Almadén according to this agreement, and Euro Chlor believes most of the central and eastern European chlorine producers will also commit to this agreement. While this agreement clearly represents an effort by all parties to responsibly address the problem of surplus mercury, some people have the view that there are not yet adequate controls on where this mercury would be sold or how it would be used.

107. Similarly, large reserve stocks of mercury held by various governments have become superfluous, and are subject to future sales on the world market if approved by the relevant national authorities. This is the case in the USA, for example, which holds a 4,435 metric ton inventory of mercury. The sale of this mercury has been suspended since 1994, awaiting a determination of its potential environmental and market impacts. Prior to that, however, the sale of some of these stocks contributed significantly to the supply of mercury on the domestic US-market, and to exports as well. US government sales were equivalent to 18 to 97 percent of the domestic US demand for mercury in the years 1990-94 (US EPA, 1997; Maxson and Vonkeman, 1996).

Uses of mercury

108. The element mercury has been known for thousands of years, fascinating as the only liquid metal, and applied in a large number of products and processes utilising its unique characteristics. Being liquid at room temperature, being a good electrical conductor, having very high density and high surface tension, expanding/contracting uniformly over its entire liquid range in response to changes in pressure and temperature, and being toxic to micro-organisms (including pathogenic organisms) and other pests, mercury is an excellent material for many purposes.

109. In the past, a number of organic mercury compounds were used quite broadly, for example in pesticides (extensive use in seed dressing among others) and biocides in some paints, pharmaceuticals and cosmetics. While many of these uses have diminished in some parts of the world, organic mercury compounds are still used for several purposes. Some examples are the use of seed dressing with mercury compounds in some countries, use of dimethylmercury in small amounts as a reference standard for some chemical tests, and thimerosal (which contains ethylmercury) used as a preservative in some vaccines and other medical and cosmetic products since the 1930’s. As the awareness of mercury's potential adverse impacts on health and the environment has been rising, the number of applications (for inorganic and organic mercury) as well as the volume of mercury used have been reduced significantly in many of the industrialised countries, particularly during the last two decades.

Examples of uses of mercury

As the metal (among others):
- for extraction of gold and silver (for centuries)
- as a catalyst for chlor-alkali production
- in manometers for measuring and controlling pressure
- in thermometers
- in electrical and electronic switches
- in fluorescent lamps
- in dental amalgam fillings

As chemical compounds (among others):
- in batteries (as a dioxide)
- biocides in paper industry, paints and on seed grain
- as antiseptics in pharmaceuticals
- laboratory analyses reactants
- catalysts
- pigments and dyes (may be historical)
- detergents (may be historical)
- explosives (may be historical)

110. However, many of the uses discontinued in the OECD countries are still alive in other parts of the world. Several of these uses have been prohibited or severely restricted in a number of countries because of their adverse impacts on humans and the environment.

111. Furthermore, while there is a general understanding of mercury production and use around the world, it is crucial to gain an even better understanding of global mercury markets and flows in order to assess demand, to design appropriate pollution prevention and reduction measures, and to monitor progress towards specific objectives.

CHAPTER 8 – Prevention and control technologies and practises

112. As noted in chapter 6, the sources of releases of mercury to the biosphere can be grouped in four major categories. Two of these categories (releases due to natural mobilisation of mercury and re-mobilisation of anthropogenic mercury previously deposited in soils, sediments and water bodies) are not well understood and largely beyond human control.

113. The other two are current anthropogenic mercury releases. Reducing or eliminating these releases may require:

- Investments in controlling releases from and substituting the use of mercury-contaminated raw materials and feedstocks, the main source of mercury releases from "unintentional" uses; and
- Reducing or eliminating the use of mercury in products and processes, the main source of releases caused by the "intentional" use of mercury.

114. The specific methods for controlling mercury releases from these sources vary widely, depending upon local circumstances, but fall generally under the following four groups:

A. Reducing mercury mining and consumption of raw materials and products that generate mercury releases;

B. Substitution (or elimination) of products, processes and practices containing or using mercury with non-mercury alternatives;

C. Controlling mercury releases through end-of-pipe techniques;

D. Mercury waste management.

115. The first two of these are "preventive" measures – preventing some uses or releases of mercury from occurring at all. The latter two are "control" measures, which reduce (or delay) some releases from reaching the environment. Within these very general groupings are a large number of specific techniques and strategies for reducing mercury releases and exposures. Whether or not they are applied in different countries depends upon government and local priorities, information and education about possible risks, the legal framework, enforcement, implementation costs, perceived benefits and other factors.

A. Reducing consumption of raw materials and products that generate mercury releases

116. Reducing consumption of raw materials and products that generate mercury releases is a preventive measure that is most often targeted at mercury containing products and processes, but may also result from improved efficiencies in the use of raw materials or in the use of fuels for power generation. This group of measures could potentially include the choice of an alternative raw material such as using natural gas for power generation instead of coal, or possibly by using a coal type with special constituents (such as more chlorine), because the mercury emissions from burning this type of coal might be easier to control than other coal types.

117. Another possible approach in some regions might be the use of coal with a lower trace mercury content (mercury concentrations appear to vary considerably in some regions depending on the origin of the raw materials). However, there are some limitations and potential problems with this approach. For example, as in the case of the utility preference for low-sulfur crude oil, it is likely that some utilities might be willing to pay more for low-mercury coal, which effectively lowers the market value of all high-mercury coal, which in turn might lead to higher consumption of high-mercury coal in regions where utilities have less rigorous emission controls. Moreover, data collected recently in the US indicate that coal supplies in the US do not vary significantly in mercury content.

118. Nonetheless, such preventive measures aimed at reducing mercury emissions are generally cost-effective, except in cases where an alternative raw material is significantly more expensive or where other problems limit this approach.

B. Substitution of products and processes containing or using mercury

119. Substitution of products and processes containing or using mercury with products and processes without mercury may be one of the most powerful preventive measures for influencing the entire flow of mercury through the economy and environment. It may substantially reduce mercury in households (and reduce accidental releases, as from a broken thermometer), the environment, the waste stream, incinerator emissions and landfills. Substitutions are mostly cost-effective, especially as they are demanded by a larger and larger market. This group of measures would also include the conversion of a fossil-fueled generating plant to a non-fossil technology.

120. At the same time, it would be a mistake to assume that substitution is always a clear winner. For example, in the case of energy-efficient fluorescent lamps, as long as there are no competitive substitutes that do not contain mercury, it is generally preferable from a product-life-cycle perspective to use a mercury-containing energy-efficient lamp rather than to use a less efficient standard incandescent lamp containing no mercury, as a result of current electricity production practises.

C. Controlling mercury emissions through end-of-pipe techniques

121. Controlling mercury emissions through end-of-pipe techniques, such as exhaust gas filtering, may be especially appropriate to raw materials with trace mercury contamination, including fossil-fueled power plants, cement production (in which the lime raw material often contains trace mercury), the extraction and processing of primary raw materials such as iron and steel, ferromanganese, zinc, gold and other non-ferrous metals and the processing of secondary raw materials such as iron and steel scrap. Existing control technologies that reduce SO_2, NO_x and PM for coal-fired boilers and incinerators, while not yet widely used in many countries, also yield some level of mercury control. For coal-fired boilers, reductions range from 0 to 96 percent, depending on coal type, boiler design, and emission control equipment. On average, the lower the coal rank, the lower the mercury reductions; however, reductions may also vary within a given coal rank. Technology for additional mercury control is under development and demonstration, but is not yet commercially deployed. In the long run, control strategies that target multiple pollutants, including SO_2, NO_x, PM and mercury, may be a cost-effective approach. However, end-of-pipe control technologies, while mitigating the problem of atmospheric mercury pollution, still result in mercury wastes that are potential sources of future emissions and must be disposed of or reused in an environmentally acceptable manner.

D. Mercury waste management

122. Mercury wastes, including those residues recovered by end-of-pipe technologies, constitute a special category of mercury releases, with the potential to affect populations far from the initial source of the mercury. Mercury waste management, the fourth "control" measure mentioned above, may consist of rendering inert the mercury content of waste, followed by controlled landfill, or it may not treat the waste prior to landfill. In Sweden, the only acceptable disposal of mercury waste now consists of "final storage" of the treated waste deep underground, although some technical aspects of this method are yet to be finalised.

123. Mercury waste management has become more complex as more mercury is collected from a greater variety of sources, including gas filtering products, sludges from the chlor-alkali industry, ashes, slags, and inert mineral residues, as well as used fluorescent tubes, batteries and other products that are often not recycled. Low concentrations of mercury in waste are generally permitted in normal landfills, while some nations only allow waste with higher mercury concentrations to be deposited in landfills that are designed with enhanced release control technologies to limit mercury leaching and evaporation. The cost of acceptable disposal of mercury waste in some countries is such that many producers now investigate whether alternatives exist in which they would not have to produce and deal with mercury waste. Mercury waste management, as it is most commonly done today, in accordance with national and local

regulations, increasingly requires long-term oversight and investment. Proper management of mercury wastes is important to reduce releases to the environment, such as those that occur due to spills (i.e. from broken thermometers and manometers) or releases that occur over time due to leakage from certain uses (e.g., auto switches, dental amalgams). In addition, given that there is a market demand for mercury, collection of mercury-containing products for recycling limits the need for new mercury mining.

Emission prevention and control measures

124. A well thought-out combination of emission prevention and control measures is an effective way to achieve optimal reduction of mercury releases. If one considers some of the more important sources of anthropogenic mercury releases, one may see how prevention and control measures might be combined and applied to these sources:

- Mercury emissions from **municipal and medical waste incinerators** may be reduced by separating the small fraction of mercury containing waste before it is combusted. For example, in the USA, free household mercury waste collections have been very successful in turning up significant quantities of mercury-containing products and even jars of elemental mercury. Also, separation programmes have proved successful in the hospital sector and a number of hospitals have pledged to avoid purchasing mercury-containing products through joint industry-NGO-Government programmes. However, separation programmes are sometimes difficult or costly to implement widely, especially when dealing with the general public. In such cases a better long-term solution may be to strongly encourage the substitution of non-mercury products for those containing mercury. As a medium term solution, separation programmes may be pursued, and mercury removed from the combustion stack gases. Mercury emissions from medical and municipal waste incineration can be controlled relatively well by addition of a carbon sorbent to existing PM and SO_2 control equipment, however, control is not 100% effective and mercury-containing wastes are generated from the process;
- Mercury emissions from **utility and non-utility boilers**, especially those burning coal, may be effectively addressed through pre-combustion coal cleaning, reducing the quantities of coal consumed through increased energy efficiency, end-of-pipe measures such as stack gas cleaning and/or switching to non-coal fuel sources, if possible. Another potential approach might be the use of coal with a lower mercury content. Coal cleaning and other pre-treatment options can certainly be used for reducing mercury emissions when they are viable and cost-effective. Also, additional mercury capture may be achieved by the introduction of a sorbent prior to existing SO_2 and PM control technologies. These technologies are under development and demonstration, but are not yet commercially deployed. Also, by-products of these processes are potential sources of future emissions and must be disposed of or reused in an environmentally acceptable manner;
- Mercury emissions due to **trace contamination of raw materials or feedstocks** such as in the cement, mining and metallurgical industries may be reduced by end-of-pipe controls, and sometimes by selecting a raw material or feedstock with lower trace contamination, if possible.
- Mercury emissions during **scrap steel production**, scrap yards, shredders and secondary steel production, result primarily from convenience light and anti-lock brake system (ABS) switches in motor vehicles; therefore a solution may include effective switch removal/collection programmes;
- Mercury releases and health hazards from **artisanal gold mining** activities may be reduced by educating the miners and their families about hazards, by promoting certain techniques that are safer and that use less or no mercury and, where feasible, by putting in place facilities where the miners can take concentrated ores for the final refining process. Some countries have tried banning the use of mercury by artisanal miners, which may serve to encourage their use of central processing facilities, for example, but enforcement of such a ban can be difficult;
- Mercury releases and occupational exposures during **chlor-alkali production** may be substantially reduced through strict mercury accounting procedures, "good housekeeping" measures to keep mercury from being dispersed, properly filtering exhaust air from the facility and careful handling and proper disposal of mercury wastes. There are a number of specific prevention methods to reduce mercury emissions to the atmosphere. The US chlor-alkali industry invented the use of ultraviolet lights to reveal mercury vapour leaks from production equipment, so that they could be plugged.

Equipment is allowed to cool before it is opened, reducing mercury emissions to the atmosphere. A continuous mercury vapour analyser can be employed to detect mercury vapour leaks and to alert workers so that they can take remedial measures. The generally accepted long-term solution is to encourage the orderly phase-out of chlor-alkali production processes that require mercury, and their substitution with technologies that are mercury free;

- Mercury releases and exposures related to mercury-containing **paints, soaps, various switch applications, thermostats, thermometers, manometers, and barometers**, as well as **contact lens solutions, pharmaceuticals and cosmetics** may be reduced by substituting these products with non-mercury products;
- Mercury releases from **dental practices** may be reduced by preparing mercury amalgams more efficiently, by substituting other materials for mercury amalgams, and by installing appropriate traps in the wastewater system;
- Mercury emissions from dental amalgams during **cremation** may only be reduced by removing the amalgams before cremation, which is not a common practice, or by filtering the gaseous emissions when the practice takes place in a crematorium. Since a flue gas cleaner is an expensive control technique for a crematorium, prevention by substituting other materials for mercury amalgams during normal dental care might be a preferred approach;
- In cases of **uncontrolled disposal of mercury-containing products or wastes**, possible reductions in releases from such practises might be obtained by making these practices illegal and adequately enforcing the law, by enhancing access to hazardous waste facilities, and, over the longer term, by reducing the quantities of mercury involved through a range of measures encouraging the substitution of non-mercury products and processes.

CHAPTER 9 - Initiatives for controlling releases and limiting use and exposures

National initiatives

125. The environmental authorities in a number of countries consider mercury to be a high-priority substance with recognised adverse effects. They are aware of the potential problems caused by use and release of mercury and mercury compounds, and therefore have implemented measures to limit or prevent certain uses and releases. Types of measures that have been implemented by various countries include:

- Environmental quality standards, specifying a maximum acceptable mercury concentration for different media such as drinking water, surface waters, air and soil and for foodstuffs such as fish;
- Environmental source actions and regulations that control mercury releases into the environment, including emission limits on air and water point sources and promoting use of best available technologies and waste treatment and disposal restrictions;
- Product control actions and regulations for mercury-containing products, such as batteries, cosmetics, dental amalgams, electrical switches, laboratory chemicals, lighting, paints/pigments, pesticides, pharmaceuticals, thermometers and measuring equipment;
- Other standards, actions and programmes, such as regulations on exposures to mercury in the workplace, requirements for information and reporting on use and releases of mercury in industry, fish consumption advisories and consumer safety measures.

126. Although legislation is the key components of most national initiatives, safe management of mercury also includes efforts to reduce the volume of mercury in use by developing and introducing safer alternatives and cleaner technology, the use of subsidies to support substitution efforts and voluntary agreements with industry or users of mercury. A number of countries have through implementation of this range of measures obtained significant reductions in mercury consumption, and corresponding reductions of uses and releases.

127. The table below gives a general overview of some of the types of implemented measures of importance to management and control of mercury, as related to its production and use life-cycle and an in-

dication of their status of implementation, based on information submitted for this report. More detailed descriptions of most of these measures are provided in chapter 9 and the separate Appendix to this report.

TYPE AND AIM OF MEASURE		STATE OF IMPLEMENTATION
Production and use phases of life cycle		
POINT SOURCES	Prevent or limit the intentional use of mercury in processes	General bans implemented in very few countries
	Prevent or limit mercury from industrial processes (such as chlor-alkali and metallurgic industry) from being released directly to the environment	Implemented in many countries, especially OECD countries
	Apply emission control technologies to limit emissions of mercury from combustion of fossil fuels and processing of mineral materials	Implemented in some OECD countries
	Prevent or limit the release of mercury from processes to the wastewater treatment system	Implemented in some OECD countries
	Prevent or limit use of obsolete technology and/or require use of best available technology to reduce or prevent mercury releases	Implemented in some countries, especially OECD countries
PRODUCTS	Prevent or limit products containing mercury from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as batteries, lighting, clinical thermometers
	Prevent products containing mercury from being exported	Only implemented in a few countries
	Prevent or limit the use of already purchased mercury and mercury-containing products	Only implemented in a few countries
	Limit the allowable content of mercury present as impurities in high-volume materials	Only implemented in a few countries
	Limit the allowed contents of mercury in commercial foodstuffs, particularly fish, and provide guidance (based on same or other limits values) regarding consumption of contaminated fish	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries.
Disposal phase of life cycle		
Prevent mercury in products and process waste from being released directly to the environment, by efficient waste collection		Implemented in many countries, especially OECD countries
Prevent mercury in products and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment		Implemented in many countries, especially OECD countries
Prevent or limit mercury releases to the environment from incineration and other treatment of household waste, hazardous waste and medical waste by emission control technologies		Implemented or implementation ongoing in some countries, especially OECD countries.
Set limit values for allowable mercury contents in sewage sludge spread on agricultural land		Implemented in a number of countries
Restrict the use of solid incineration residues in road building, construction and other applications		Implemented in some OECD countries
Prevent the re-marketing of used, recycled mercury		Only implemented in a few countries

Regional and international initiatives

128. It is also apparent that because of mercury's persistence in the environment and the fact that it is transported over long distances by air and water, crossing borders and often accumulating in the food chain far from it's original point of release, a number of countries have concluded that national measures are not sufficient. There are a number of examples where countries have initiated measures at regional, sub-regional and international levels to identify common reduction goals and ensure coordinated implementation among countries in the target area.

129. Three regional, legally binding instruments exist that contain binding commitments for parties with regards to reductions on use and releases of mercury and mercury compounds:

- LRTAP Convention on Long-Range Transboundary Air Pollution and its 1998 Aarhus Protocol on Heavy Metals (for Central and Eastern Europe and Canada and the USA);
- OSPAR Convention for Protection of the Marine Environment of the North-East Atlantic; and
- Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea.

All these three instruments have successfully contributed to substantial reductions in use and releases of mercury within their target regions.

130. The regional and sub-regional cooperation is, however, not limited to legally binding agreements. Six initiatives exist at regional or sub-regional levels that inspire and promote cooperative efforts to reduce uses and releases of mercury within the target area without setting legally binding obligations on the countries/regions participating. The initiatives are: the Arctic Council Action Plan, the Canada-US Great Lakes Binational Toxics Strategy, the New England Governors/Eastern Canada Premiers Mercury Action Plan, the North American Regional Action Plan, the Nordic Environmental Action Programme and the North Sea Conferences. Important aspects of these initiatives are the discussion and agreement on concrete goals to be obtained through the cooperation, the development of strategies and work plans to obtain the set goals and the establishment of a forum to monitor and discuss progress. Although these initiatives are not binding on their participants, there is often a strong political commitment to ensure that the agreements reached within the initiative are implemented at national/regional level.

131. There are also a number of examples of national/regional initiatives being taken by the private sector in the form of voluntary commitments that can be seen as an adjunct to public sector initiatives and as having a good chance of success as they have, by definition, the support of the primary stakeholders. All these voluntary initiatives are valuable supplements to national regulatory measures and facilitate awareness raising, information exchange and the setting of reduction goals that benefit the target region.

132. At the international level, two multilateral environmental agreements (MEAs) exist that are of relevance to mercury and mercury compounds: the Basel Convention on Control of Transboundary Movements of Hazardous Wastes and their Disposal and the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Chemicals and Pesticides in International Trade. These instruments regulate trade in unwanted chemicals/pesticides or hazardous wastes. However, they do not contain specific commitments to reduce uses and releases of mercury directly. The most recently negotiated agreement relevant to chemicals, the Stockholm Convention on POPs, does not cover mercury. In addition, a number of international organizations have ongoing activities addressing the adverse impacts of mercury on humans and the environment.

133. A more detailed compilation of national initiatives, including legislation, in each individual country is contained in an appendix to this report, entitled “Overview of existing and future national actions, including legislation, relevant to mercury”. The Appendix is published in a separate document. The information compiled therein has been extracted from the national submissions received from countries under this project.

CHAPTER 10 – Data gaps

National research and information needs

134. A number of countries have in their submissions to UNEP expressed a need for establishing or improving their national “database” (i.e. knowledge of and information on uses and emissions, sources of releases, levels in the environment and prevention and control options) on mercury and mercury compounds. Although the situation varies from country to country, there seems to be a general need for information relevant to the various elements of an environmental management strategy for mercury. Also, countries with a longer tradition of environmental management of mercury have expressed the need to continue to expand their knowledge base on mercury to improve risk assessment and ensure effective risk management. Some of the needs include, among others:

- Inventories of national use, consumption and environmental releases of mercury;
- Monitoring of current levels of mercury in various media (such as air, air deposition, surface water) and biota (such as fish, wildlife and humans) and assessment of the impacts of mercury on humans and ecosystems, including impacts from cumulative exposures to different mercury forms;
- Information on transport, transformation, cycling, and fate of mercury in various compartments;
- Data and evaluation tools for human and ecological risk assessments;
- Knowledge and information on possible prevention and reduction measures relevant to the national situation;
- Public awareness-raising on the potential adverse impacts of mercury and proper handling and waste management practises;
- Appropriate tools and facilities for accessing existing information relevant to mercury and mercury compounds at national, regional and international levels;
- Capacity building and physical infrastructure for safe management of hazardous substances, including mercury and mercury compounds, as well as training of personnel handling such hazardous substances.
- Information on the commerce and trade of mercury and mercury-containing materials.

135. In principle, some parts of this information might be exchanged nationally, regionally or internationally, as its relevance is often universal, however, it might need to be “translated” into the context of the individual country’s framework of traditions, economic and industrial activities and political reality. This, in itself, demands a substantial degree of priority, knowledge and funding. Other parts of the information are country specific and would require national efforts to research, collect and process the information.

Data gaps of a general, global character

136. Although mercury is probably among the best-studied environmental toxicants, there are data gaps in the basic understanding of a number of general, global issues relevant to mercury. Based on submitted information and the compilation and evaluation hereof, a possible division of current data gaps of global relevance on mercury could be as follows (not in order of priority):

- Understanding and quantification of the **natural mechanisms affecting the fate of mercury** in the environment, such as mobilisation, transformation, transports and intake. In other words, the pathways of mercury in the environment, and from the environment to humans.
- Understanding and quantification – in a global perspective – of the **human conduct in relation to mercury releases**, and the resulting human contributions to the local, regional and global mercury burden. In other words, the pathways of mercury from humans to the environment.
- Understanding of how and to what degree humans, ecosystems and wildlife are **adversely affected by the current mercury levels** found in the local, regional and global environment. In other words, the possible effects, number affected, and the magnitude and severeness in those affected.

137. A basic understanding has been established for all three categories mentioned above, based on about half a century's extensive research on the impacts and pathways of mercury. However, in a number of areas, further research is needed to provide new information to improve environmental modelling assessments and modern decision-making tools. Despite these gaps in information, a sufficient understanding has been developed of mercury (including knowledge of its fate and transport, health and environmental impacts, and the role of human activity) that international action to address the global adverse impacts of mercury should not be delayed.

CHAPTER 11 – Options for addressing any significant global adverse impacts of mercury

138. The UNEP Governing Council requested, as part of the global assessment on mercury, an outline of options for consideration by the Governing Council, addressing any significant global adverse impacts of mercury, inter alia, by reducing and or eliminating the use, emissions, discharges and losses of mercury and its compounds; improving international cooperation; and ways to enhance risk communication.

139. As part of the implementation of Governing Council decision 21/5, UNEP established a Working Group to assist it in preparing for the Governing Council's discussions on the issue at its session in February 2003. The Global Mercury Assessment Working Group, at its first meeting held from 9 to 13 September 2002, finalized this assessment report for presentation to the Governing Council at its 22nd session. At this meeting, the Working Group arrived at a number of conclusions of relevance to the Governing Council's considerations:

- Based on the key finding of this report, the Working Group concluded that, in its view, there was sufficient evidence of significant global adverse impacts to warrant international action to reduce the risks to human health and/or the environment arising from the release of mercury into the environment. While it was important to have a better understanding of the issue, the Working Group emphasized that it was not necessary to have full consensus or complete evidence in order to take action and therefore potentially significant global adverse impacts should also be addressed.

- The Working Group also agreed on an outline of options for recommendation on measures to address global adverse impacts of mercury at the global, regional, national and local levels. The options include measures such as reducing or eliminating the production, consumption and releases of mercury, substituting other products and processes, launching negotiations for a legally-binding treaty, establishing a non-binding global programme of action, and strengthening cooperation amongst governments on information-sharing, risk communication, assessment and related activities.

- Finally, the Working Group agreed to the need to submit to the Governing Council a range of possible immediate actions in light of their findings on the impacts of mercury, such as increasing protection of sensitive populations (through enhanced outreach to pregnant women and women planning to become pregnant), providing technical and financial support to developing countries and to countries with economies in transition, and supporting increased research, monitoring and data-collection on the health and environmental aspects of mercury and on environmentally friendly alternatives to mercury.

1 Introduction

1.1 Background and mandate

140. This report responds to the request of the Governing Council of the United Nations Environment Programme (UNEP), through GC decision 21/5, that UNEP undertake a global assessment of mercury and mercury compounds, in cooperation with other members of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), to be presented to the Governing Council at its 22nd session in 2003. The assessment would include contributions from Governments, intergovernmental and non-governmental organizations and the private sector, and cover the following elements:

(a) To summarize existing information including recent authoritative reviews of the chemistry, including transformation and methylation processes, toxicology, and impacts of mercury on human health and the environment;

(b) To compile and summarize existing information concerning the global natural and anthropogenic sources of mercury;

(c) To consolidate and analyse information regarding relevant environmental long-range transport and the origin, pathways, deposition and transformation of these substances on a global scale;

(d) To examine and describe the sources of release of mercury to the environment, and the current production and use patterns of mercury as a global commodity;

(e) To compile and summarize information about prevention and control technologies and practices, and their associated costs and effectiveness, that could reduce and/or eliminate releases of mercury, including the use of suitable substitutes, where applicable;

(f) To describe ongoing actions and compile information about future plans at the national, subregional or regional levels for controlling releases, and limiting use and exposures, including waste management practices;

(g) To outline options for consideration at the twenty-second session of the Governing Council/Global Ministerial Environment Forum addressing any significant global adverse impacts of mercury, inter alia, by reducing and or eliminating the use, emissions, discharges and losses of mercury and its compounds; improving international cooperation; and ways to enhance risk communication; and

(h) To provide, for elements (a) through (f), a summary description of scientific and technical information needs and data gaps.

141. The Governing Council requested UNEP to report on the results of the assessment to the Governing Council at its 22nd session, and also agreed to consider whether there is a need for assessments of other heavy metals of possible global concern at that session.

142. In this assessment report, the specific elements listed by the UNEP Governing Council in its decision 21/5 are covered as follows:

- Element (a) is covered in chapters 2, 3, 4 and 5;
- Element (b) is covered in chapter sections 6.1, 6.2 and 6.3;
- Element (c) is covered in chapter section 6.4;
- Elements (d), (e) and (f) are covered by chapters 7, 8 and 9 respectively;
- Element (g) is covered by chapter 11; and
- Element (h) is covered by chapter 10.

1.2 Submission of information for this report

143. UNEP, in April 2001, as a follow-up to the request from the Governing Council, invited Governments, intergovernmental and non-governmental organizations and the private sector to submit information relevant to mercury and mercury compounds. As information was received, it was as far as possible posted on the Global Mercury Assessment web site at http://www.chem.unep.ch/mercury/, specially established for the purpose of allowing insight into the information collected. For submitted reports and articles protected by copyright laws, respective copyright rules were observed.

144. As of 16 September 2002, 81 Governments plus the European Commission on behalf of the European Union (EU), 10 intergovernmental and 12 non-governmental organizations had submitted information for or comments to this report. The distribution of submissions from Governments between different geographic regions is shown in Figure 1.1.

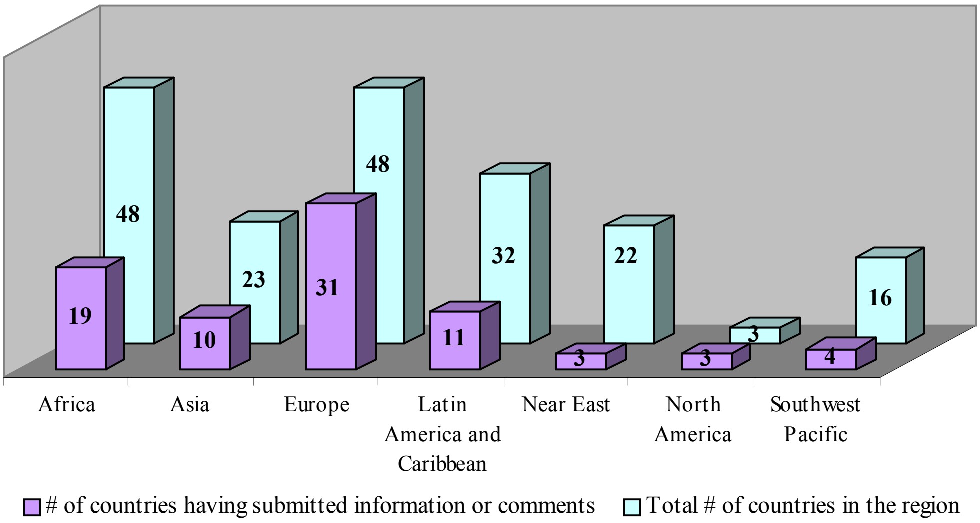
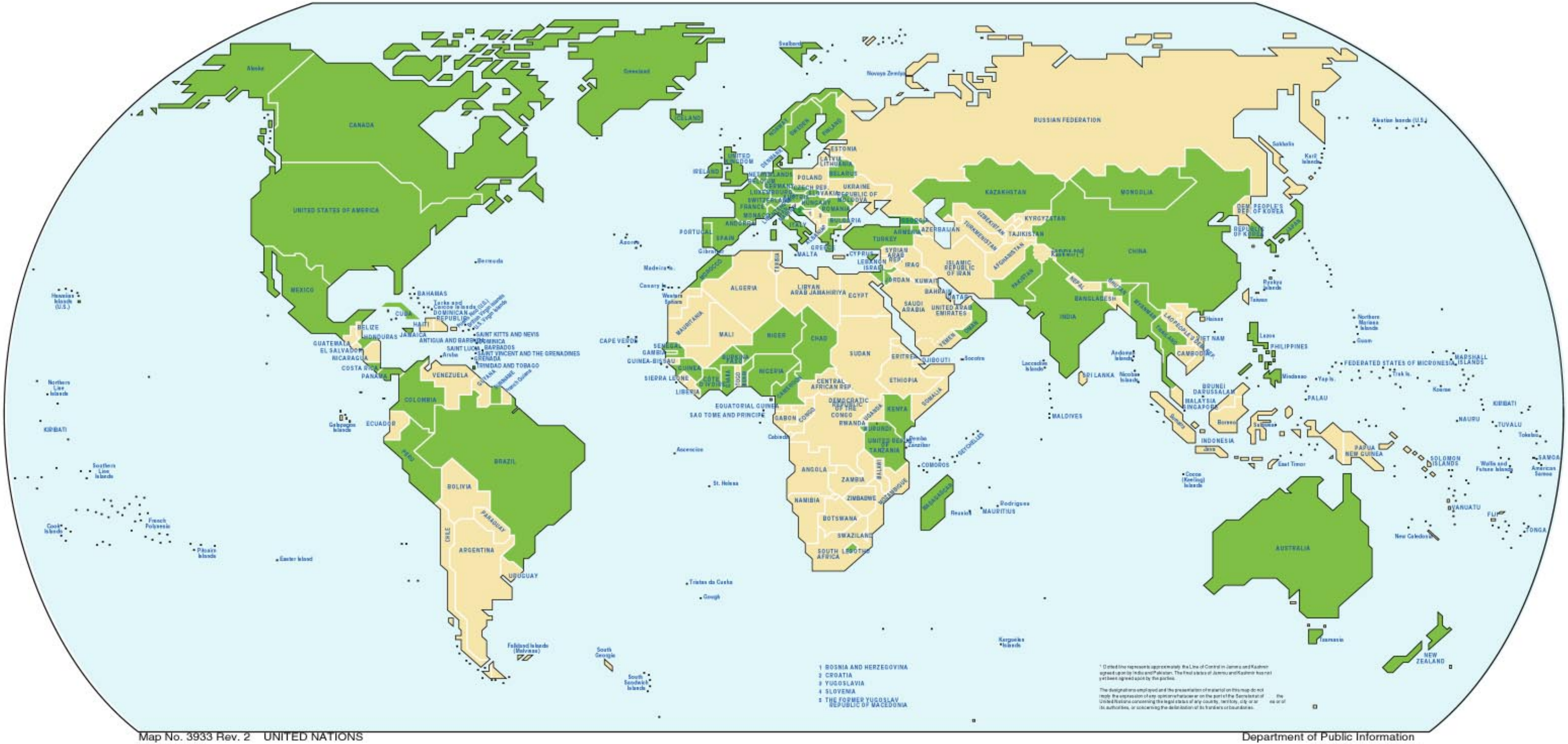


Figure 1.1 Overview of submissions to the Global Mercury Assessment, by geographic region.

145. Figure 1.2 illustrates the global coverage of the information or comments submitted from Governments. A list of information submissions and a list of comments to the first draft of this report are available in documents separate from this report; further details on the individual Governments, intergovernmental and non-governmental organizations that have submitted information or comments can be found there. In these lists, each submission or comment has been given a specific number, so that a reference can be provided for the information used in this report.

146. Although a relatively large number of Governments submitted information for the report, it should be noted that there were substantial differences in the amount of information available from each Government. Some Governments, especially those of OECD-countries, have comprehensive inventories that document mercury production, use and releases over a number of years, while others, although they are aware of mercury use in their country, have very limited documented data.



Map No. 3933 Rev. 2 UNITED NATIONS
August 1999

Department of Public Information
Cartographic Section

Figure 1.2 Submissions from Governments to the Global Mercury Assessment – global coverage.

1.3 Sources of information for this report

147. The sources of information used to develop this report are:

- Submissions from Governments, intergovernmental and non-governmental organizations and the private sector, received as of 2 April 2002;
- Additional publications, articles and reports of relevance to mercury identified through a literature search in scientific literature;
- Additional information, publications and reports publicly available on websites of various Governments, intergovernmental and non-governmental organizations; and
- Comments and additions provided by members of the Global Mercury Assessment Working Group after circulation of a first draft of this report and during the review of the revised draft report at the Global Mercury Assessment Working Group meeting that took place in Geneva, Switzerland from 9-13 September 2002.

148. References for the information used to develop this report are given as far as possible in the text. If no specific reference is provided, it has been found in the submission provided by the specific Government or organization.

149. Because of the large volume of reports, articles, abstracts, etc. relating to mercury that were submitted/collected, it was not possible to review all the information in detail in the time available. The information was screened and a prioritisation was made. Focus was given to country-specific information that might add to the global understanding of the use and regulation of mercury, especially from non-OECD countries, and information that might add to the general knowledge of the various issues linked to mercury, based on the recently published authoritative reviews on such issues.

150. As this report should provide a global overview, summarising the issues related to mercury, there are substantial amounts of detailed information dealing with various aspects that have not been included, such as detailed national mercury consumption and use data. This information might, however, be a basis for further, detailed review and analysis later should a decision on further work be taken.

1.4 Scope and coverage in this report

151. Although this report is entitled “Global Mercury Assessment”, it does not assess mercury in the true meaning of the word – to judge or decide the amount, value, quality or importance of (Cambridge International Dictionary of English, 1995). It is not a scientific analysis of the toxicology of mercury and mercury compounds, its effects on human health or the environment and environmental long-range transport and pathways, nor a global assessment of the risks related to use and releases of mercury.

152. Rather, it attempts, for each element identified by the Governing Council, to compile and provide, as far as possible, a global overview of evaluations and assessments already made and conclusions already drawn by the scientific community, national Governments, organizations, etc on the various issues related to mercury. Although this report has not been independently peer-reviewed, it has been extensively reviewed by the Global Mercury Assessment Working Group and is considered to be a useful summary of current science and other topics relevant to mercury. The report draws mainly on recently published authoritative reviews on the various topics relevant to mercury, supplemented by national information. As a large part of the previously published reviews focus on OECD-countries, where much of the current research is ongoing and some reduction measures implemented, an attempt has been made to identify and include relevant information from non-OECD countries.

153. As this report attempts to provide a global overview of the issues related to mercury on a limited number of pages, all the information submitted by each individual country or organization cannot be reflected. However, certain compilations have been developed that contain comprehensive national

information on certain specific issues, such as regulatory actions. If they are found useful, these might be kept updated in future.

154. To facilitate reading, in each chapter an overview of the main points in the chapter is given at the very beginning of the chapter. In addition, the section entitled "Summary of the report" at the beginning of the report constitutes a summary of the information in each chapter. A summary of the key findings of the report is also included at the very beginning of the report. When reading the full report, readers might notice that there is some overlap in the information in some of the sections. However, this was deemed necessary, as it is assumed that in the future that many of the sections might be read separately by a reader interested in a specific topic.

155. The report was originally drafted by two environmental consulting companies, COWI Consulting Engineers and Planners AS in Denmark and Concorde East/West in Belgium, with COWI as the project manager. The main contributor in each company was Mr. Jakob Maag and Mr. Peter Maxson, respectively. Both have extensive experience and have previously been involved in a number of publications relevant to mercury, both at national and international level. Within UNEP Chemicals, Ms. Aase Tuxen coordinated the work and, together with Mr. Charles French, contributed to the drafting, editing and finalization of the report.

1.5 Purpose of this report

156. As part of the implementation of Governing Council decision 21/5, UNEP established a Working Group to assist it in preparing for the Governing Council's discussions on the issue at its session in February 2003. The Global Mercury Assessment Working Group was open-ended and consisted of members nominated by Governments, intergovernmental organizations and non-governmental organizations. Working Group members assisted in the drafting and finalization of this report, first through a comment round by mail, then through a meeting of the Working Group, which took place 9-13 September 2002 in Geneva, Switzerland.

157. The Working Group reviewed the draft assessment report and agreed to a number of changes and enhancements. It also identified the key findings of importance and finalized the assessment report for submission to the Governing Council. Based on the key finding of this report, the Working Group concluded that, in its view, there was sufficient evidence of significant global adverse impacts to warrant international action to reduce the risks to human health and/or the environment arising from the release of mercury into the environment. It agreed on an outline of possible options to address these global adverse impacts of mercury at the global, regional, national and local levels. Finally, the Working Group agreed to the need to submit to the Governing Council a range of possible immediate actions in light of their findings on the impacts of mercury. The conclusions of the Working Group are outlined in chapter 11 of this report.

158. This report will be forwarded to the Governing Council for consideration at its 22nd session. By having initiated the development of this assessment report and the outline of options, the Governing Council will have a better basis for considering if any international action on mercury is called for in order to promote environmentally sound management of mercury and its compounds. The assessment report will contribute to increased awareness and understanding among decision makers of the major issues related to mercury and its compounds, thereby facilitating the debate on the issue at the next session of the Governing Council.

159. The results of the Governing Council's discussions on the issue during its 22nd session will be available on the Global Mercury Assessment website at http://www.chem.unep.ch/mercury/ once the session has taken place.

2 Chemistry

2.1 Overview

160. Mercury occurs naturally in the environment and exists in a large number of forms. Like lead or cadmium, mercury is a constituent element of the earth, a heavy metal. In pure form, it is known alternatively as “elemental” or “metallic” mercury (also expressed as Hg(0) or Hg^0). Mercury is rarely found in nature as the pure, liquid metal, but rather within compounds and inorganic salts. Mercury can be bound to other compounds as monovalent or divalent mercury (also expressed as Hg(I) and Hg(II) or Hg^{2+}, respectively). Many inorganic and organic compounds of mercury can be formed from Hg(II).

161. Elemental mercury is a shiny, silver-white metal that is a liquid at room temperature and is traditionally used in thermometers and some electrical switches. If not enclosed, at room temperature some of the metallic mercury will evaporate and form mercury vapours. Mercury vapours are colourless and odourless. The higher the temperature, the more vapours will be released from liquid metallic mercury. Some people who have breathed mercury vapours report a metallic taste in their mouths.

162. Mercury is mined as mercuric sulfide (cinnabar) ore. Through history, deposits of mercuric sulphide have been the source ores for commercial mining of metallic mercury. The metallic form is refined from mercuric sulfide ore by heating the ore to temperatures above 540 ºC. This vaporises the mercury in the ore, and the vapours are then captured and cooled to form the liquid metal mercury.

163. Inorganic mercuric compounds include mercuric sulfide (HgS), mercuric oxide (HgO) and mercuric chloride ($HgCl_2$). These mercury compounds are also called mercury salts. Most inorganic mercury compounds are white powders or crystals, except for mercuric sulphide, which is red and turns black after exposure to light. Some mercury salts (such as $HgCl_2$) are sufficiently volatile to exist as an atmospheric gas. However, the water solubility and chemical reactivity of these inorganic (ionic) mercury gases lead to much more rapid deposition from the atmosphere than for elemental mercury. This results in significantly shorter atmospheric lifetimes for these ionic (e.g. divalent) mercury gases than for the elemental mercury gas.

164. When mercury combines with carbon, the compounds formed are called "organic" mercury compounds or organomercurials. There is a potentially large number of organic mercury compounds (such as dimethylmercury, phenylmercury, ethylmercury and methylmercury); however, by far the most common organic mercury compound in the environment is methylmercury. Like the inorganic mercury compounds, both methylmercury and phenylmercury exist as "salts" (for example, methylmercuric chloride or phenylmercuric acetate). When pure, most forms of methylmercury and phenylmercury are white crystalline solids. Dimethylmercury, however, is a colourless liquid.

165. Several forms of mercury occur naturally in the environment. The most common natural forms of mercury found in the environment are metallic mercury, mercuric sulphide, mercuric chloride and methylmercury. Some micro-organisms and natural processes can change the mercury in the environment from one form to another.

166. Elemental mercury in the atmosphere can undergo transformation into inorganic mercury forms, providing a significant pathway for deposition of emitted elemental mercury.

167. The most common organic mercury compound that micro-organisms and natural processes generate from other forms is methylmercury. Methylmercury is of particular concern because it can build up (bioaccumulate and biomagnify) in many edible freshwater and saltwater fish and marine mammals to levels that are many thousands of times greater than levels in the surrounding water.

168. Methylmercury can be formed in the environment by microbial metabolism (biotic processes) and by chemical processes that do not involve living organisms (abiotic processes). Although, it is generally believed that its formation in nature is predominantly due to biotic processes. Significant direct anthropogenic (or human-generated) sources of methylmercury are currently not known, although historic sources have existed. Indirectly, however, anthropogenic releases contribute to the methylmercury levels found in nature because of the transformation of other forms. Examples of direct release of organic mercury compounds are the Minamata methylmercury-poisoning event that occurred in the 1950's where organic mercury by-products of industrial-scale acetaldehyde production were discharged in the local bay, and the Iraqi poisoning events where wheat treated with a seed dressing containing organic mercury compounds were used for bread. Also, new research has shown that methylmercury can be released directly from municipal waste landfills (Lindberg *et al.*, 2001) and sewage treatment plants (Sommar *et al.*, 1999), but the general significance of this source is still uncertain.

169. Being an element, mercury cannot be broken down or degraded into harmless substances. Mercury may change between different states and species in its cycle, but its simplest form is elemental mercury, which itself is harmful to humans and the environment. Once mercury has been liberated from either ores or from fossil fuel and mineral deposits hidden in the earth's crust and released into the biosphere, it can be highly mobile, cycling between the earth's surface and the atmosphere. The earth's surface soils, water bodies and bottom sediments are thought to be the primary biospheric sinks for mercury.

Mercury exists in the following main states under natural conditions

- As metallic vapour and liquid/elemental mercury;
- Bound in mercury containing minerals (solid);
- As ions in solution or bound in ionic compounds (inorganic and organic salts);
- As soluble ion complexes;
- As gaseous or dissolved non-ionic organic compounds;
- Bound to inorganic or organic particles/matter by ionic, electrophilic or lipophilic adsorption.

Significance of mercury speciation

170. Different forms mercury exists in (such as elemental mercury vapour, methylmercury or mercuric chloride) are commonly designated "species". As mentioned above, the main groups of mercury species are elemental mercury, inorganic and organic forms. Speciation is the term commonly used to represent the distribution of a quantity of mercury among various species.

171. Speciation plays an important part in the toxicity and exposure of mercury to living organisms. Among other things, the species influence:

- The physical availability for exposure - if mercury is tightly bound to in-absorbable material, it cannot be readily taken up (e.g. into the blood stream of the organism);
- The internal transport inside the organism to the tissue on which it has toxic effects - for example the crossing of the intestinal membrane or the blood-brain barrier;
- Its toxicity (partly due to the above mentioned);
- Its accumulation, bio-modification, detoxification in – and excretion from – the tissues;
- Its bio-magnification on its way up the trophic levels of the food chain (an important feature particularly for methylmercury).

172. Speciation also influences the transport of mercury within and between environmental compartments including the atmosphere and oceans, among others. For example, the speciation is a determining factor for how far from the source mercury emitted to air is transported. Mercury adsorbed on particles and ionic mercury compounds will fall on land and water mainly in the vicinity of the sources (local to regional distances), while elemental mercury vapour is transported on a hemispherical/global

scale making mercury emissions a global concern. Another example is the so-called "polar sunrise mercury depletion incidence", where the transformation of elemental mercury to divalent mercury is influenced by increased solar activity and the presence of ice crystals, resulting in a substantial increase in mercury deposition during a three month period (approximately March to June).

173. Moreover, speciation is very important for the controllability of mercury emissions to air. For example, emissions of inorganic mercuric compounds (such as mercuric chloride) are captured reasonably well by some control devices (such as wet-scrubbers), while capture of elemental mercury tends to be low for most emission control devices.

2.2 Mercury species and transformation in the atmosphere

174. The atmospheric chemistry of mercury involves several interactions:

- Gas phase reactions;
- Aqueous phase reactions (in cloud and fog droplets and deliquesced aerosol particles);
- Partitioning of elemental and oxidised mercury species between the gas and solid phases;
- Partitioning between the gas and aqueous phases; and also
- Partitioning between the solid and aqueous phases in the case of insoluble particulate matter scavenged by fog or cloud droplets.

175. The interplay between mercury atmospheric processes and chemistry is summarised in figure 2.1 below. The atmospheric speciation plays an important role in the long-range transport of mercury, as well as in deposition mechanisms. Atmospheric mercury transport is described in chapter 6.

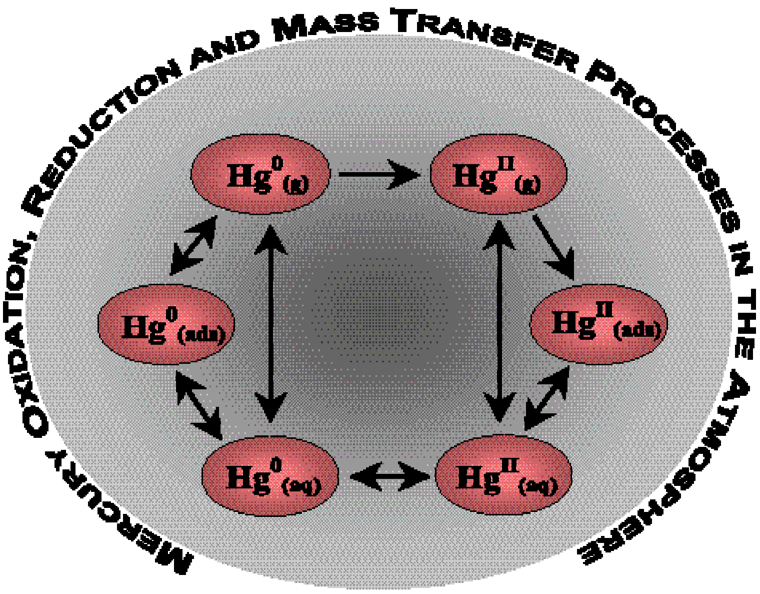


Figure 2.1 Model of interactions between mercury species in the atmosphere. (Frontispiece of the 2001 Special Issue of Atmospheric Environment (vol. 35, no. 17) dedicated to mercury research in Europe.) (Pirrone et al.*, 2001a)*

176. Since the first serious attempt at modelling the atmospheric chemistry and speciation of mercury within the framework of a tropospheric photochemical box model, which included fog and cloud chemistry as well as particulate matter (Pleijel and Munthe, 1995), a number of additional mercury atmospheric reaction parameters have been measured and two major reviews of atmospheric chemistry have been published (Schroeder and Munthe, 1998; Lin and Pekhonen, 1999).

177. The determination of the Hg(0)+ OH (hydroxyl radical) gas phase rate constant (Sommar *et al*., 2001; Ariya *et al*., 2002) and the very recent measurements of Hg+ halide atom rate constants (Ariya *et al*., 2002) has shown that the oxidation of elemental mercury (previously thought to occur mostly in the aqueous phase, and only slowly in the gas phase as a result of reaction with O_3), in fact occurs relatively rapidly, and estimates of the atmospheric lifetime of elemental mercury have had to be reduced from around a year to matter of a few months. The rate of oxidation of elemental mercury is fundamental to atmospheric mercury chemistry because the oxidised mercury compounds (such as HgO and $HgCl_2$) produced are more soluble (and so are readily scavenged by clouds), less volatile (and therefore more rapidly scavenged by particulates), and have a higher deposition velocity. Thus oxidation may increase dry and wet deposition fluxes and also deposition via PM. Oxidised mercury can also be reduced to elemental mercury in atmospheric droplets, thus limiting the overall rate of oxidation and deposition. The quantitative description of these processes is associated with some uncertainty. (Munthe *et al.*, 1991)

178. A simplified version of atmospheric mercury chemistry has been used by Petersen *et al*. (1998) in a regional scale dispersion/meteorological model. While such a model can provide a reasonable approximation of mercury transport and deposition, recent developments noted above on the reaction of elemental mercury with both halides and hydroxyl radicals indicate that these reactions must be incorporated in order to improve model accuracy. The hydroxyl reaction has been included in a Chemical Transport Model (Bergan and Rohde, 2001), however, the results suggested that perhaps the rate constant from Sommar *et al*. (2001) was too high, whereas recently published results from Ariya *et al*. (2002) suggest that it may be too low. Clearly, if atmospheric oxidation processes are faster than previously thought, then in order for the hemispherical background concentration to remain as stable as it does, emission (or re-emission) of Hg(0), most probably from the sea, also occurs at a faster rate than once supposed.

179. The tropospheric chemistry of mercury has been much discussed in the last four or five years since the publication of the results of long term measurements from the Arctic, (Shroeder *et al*., 1998) where contemporaneously with tropospheric ozone depletion events, seen periodically after polar dawn, the concentration of Hg(0) diminished to as low as 10-20 percent of its typical value over a period of three or four days. Since then this phenomenon has been confirmed by further measurements of the concentration of Hg(0) and also of gas phase oxidised mercury compounds (Lindberg *et al*., 2002a) and mercury associated with particulate matter (Lu *et al*., 2001), and mercury depletion has also been seen in Antarctica (Ebinghaus *et al*., 2002). The results are consistent with gas phase oxidation of Hg(0), probably by halogen atoms or halogen containing radicals (Boudries and Bottenheim, 2000), and subsequent condensation on to particulates or deposition to the snow pack. This phenomenon has naturally caused concern due to the possible toxicological effects of increased mercury input to a fragile ecosystem at the time in which biological activity is increasing after the long polar night.

180. Another region of much interest in terms of the tropospheric chemistry of mercury is the Marine Boundary Layer (MBL, i.e. the air directly above the sea surface). Studies performed during European projects have shown that the concentrations of oxidised mercury are as high in the Mediterranean area as they are in the more industrial areas of northern Europe (Pirrone *et al*., 2001b; Wangberg *et al*., 2001, AE special issue). This fact is another example of how the accepted view of mercury atmospheric chemistry has changed in the last few years. At one time it was assumed that most if not all gas phase oxidised mercury was due to direct emission from industrial sources, and that given its solubility and higher deposition velocity, oxidised mercury would not be found very far from these sources. Thus, the presence of these compounds in the open sea of the Mediterranean during anticyclonic conditions when transport is negligible (Sprovieri *et al*., 2002) would not have been expected.

181. Recent modelling studies of mercury chemistry in the MBL suggest an important role for sea salt aerosol in mercury cycling (Hedgecock and Pirrone, 2001; Hedgecock *et al*., 2002). The presence of deliquesced sea-salt aerosol in the MBL provides both a scavenging phase for oxidised mercury compounds resulting from the gas phase oxidation of Hg(0) and also an almost unlimited supply of chloride ions with which mercury can form aqueous phase complexes resulting in high aqueous phase

concentrations of Hg(II) in solution (Pirrone *et al.*, 2000). Interestingly, many of the abrupt changes in tropospheric photochemistry seen at polar dawn are repeated on a lesser scale each day in the MBL, as shown by the recent discovery of sunrise ozone destruction in the MBL, (Nagao *et al.*, 1999). It is most likely therefore that the same reactions which result in polar mercury depletion events, occur daily in the MBL, hence the presence of notable concentrations of oxidised mercury compounds in the MBL. The diurnal variation of Hg(II) compound concentrations (Sprovieri *et al.*, 2002; Hedgecock *et al.*, 2002) shows that oxidation is slower at night and also that deposition is constantly removing these compounds from the atmosphere, and thus mercury must be replenished either from the sea or the free troposphere at more or less the same rate.

182. Axenfeld *et al.* (1991, as quoted by Pirrone *et al.*, 2001) concluded that as much as 60 percent of the anthropogenic emissions in Europe were in gaseous elemental form, 30 percent as gaseous divalent mercury and 10 percent as elemental mercury on particles.

183. Most of the emissions from combustion of fuels (an important source of emissions) occur in the gaseous phase. In the combustion zone, mercury present in coal and other fossil fuels is thermally converted into the elemental form. While in the flue gases, some of it may be oxidised, depending on the presence of oxidizing constituents such as chlorine. The oxidised form can be retained in modern flue gas cleaning systems. The emission generation process for mercury during incineration of wastes is similar, except that more mercury in the oxidised form is expected from incinerators, due to the higher content of chlorine in waste matter than in fossil fuels (AMAP, 1998).

184. In table 2.1 an overview of the speciation of emissions from a number of major anthropogenic source types is given. The table was prepared by Pirrone *et al.* (2001).

Table 2.1 Emission profiles (fraction of the total) of mercury from anthropogenic sources, 1995 (table from Pirrone et al.*, 2001).*

Species	**Coal Combustion Power Plants**	**Coal Combustion Residential Heat**	**Oil Combustion**	**Cement Production**	**Non-Ferrous Metals**	**Pig & Iron**	**Chlor-alkali**	**Waste Incineration**	**Other**	**Average of all sources**	**Information Source**
Hg^0 (gas)	0.5	0.5	0.5	0.8	0.6	0.8	0.7	0.2	0.8	0.64	Pacyna *et al.*, 2000
Hg(II)	0.4	0.4	0.4	0.15	0.3	0.15	0.3	0.6	0.15	0.285	Modified by Pacyna, 1998
Hg (partic.)	0.1	0.1	0.1	0.05	0.1	0.05	0	0.2	0.05	0.075	

185. Recent industrial source monitoring studies in the United States have found emission profiles that differ from the fractions displayed in this table. For the production of chlorine and caustic soda (mercury-based chlor-alkali production), US studies have found a significantly higher fraction of mercury emitted as Hg^0 gas. For waste incineration, these studies have found nearly all mercury emissions in the form of Hg(II) gas from medical waste incinerators. Also, direct emissions of particulate mercury from most industrial sources have been found to be negligible, only a few percent at most. However, a considerable fraction of Hg(II) gas emissions may adsorb to atmospheric particulate matter. Updated information regarding mercury emission speciation for waste incineration and cement production can be found in US EPA Technical Report EPA/600/R-00/102. Updated information on coal combustion is also available in the scientific literature and some new EPA/DOE reports (see Prestbo and Bloom, 1995). Updated information on chlor-alkali factory emissions is available from US EPA Technical Report EPA/600/R-02-007a.

2.3 Mercury species and transformation in aquatic environments

186. Methylmercury can be formed in the environment by microbial metabolism (biotic processes) such as by certain beacteria and by chemical processes that do not involve living organisms (abiotic processes). The formation of methylmercury in aquatic systems is influenced by a wide variety of environmental factors. The efficiency of microbial mercury methylation generally depends on factors such as microbial activity and the concentration of bioavailable mercury (rather than the total mercury pool), which in turn are influenced by parameters such as temperature, pH, redox potential and the presence of inorganic and organic complexing agents. (Ullrich *et al*., 2001)

187. Certain bacteria also demethylate mercury and this tendency increases given increasing levels of methylmercury, thereby forming some natural constraints on build-up of methylmercury (Marvin-Dipasquale *et al.*, 2000, Bailey *et al.*, 2001). Since both methylation and demethylation processes occur, environmental methylmercury concentrations reflect net methylation rather than actual rates of methylmercury synthesis. Numerous bacterial strains capable of demethylating methylmercury are known, including both aerobic and anaerobic species, but demethylation appears to be predominantly accomplished by aerobic organisms. Bacterial demethylation has been demonstrated both in sediments and in the water column of freshwater lakes. Degradation of methyl and phenyl mercury by fresh water algae has also been described. (Ullrich *et al*., 2001)

188. Purely chemical methylation of mercury is also possible if suitable methyl donors are present. The relative importance of abiotic versus biotic methylation mechanisms in the natural aquatic environment has not yet been established, but it is generally believed that mercury methylation is predominantly a microbially mediated process (Ullrich *et al.,* 2001). For more details on mercury methylation in the aquatic environment and the factors affecting it, see the recent review by Ullrich *et al.* (2001).

189. Methylmercury is the predominant mercury species in fish. The US EPA states in an updated mercury overview paper that in most adult fish, 90 to 100 percent of mercury content is methylmercury (US EPA, 2001a). As a consequence, the US EPA recommends that the cheaper total mercury chemical analysis be used for (state) evaluation of risk from consuming local fish, and that results should be used as if mercury was present as 100 percent methylmercury in order to be most protective of human health.

190. Mason and Fitzgerald (1996; 1997) have reviewed aspects of the cycle of mercury in oceans and other waters. From open ocean studies, it is apparent that elemental mercury, dimethylmercury and, to a lesser extent, methylmercury are common constituents of the dissolved mercury pool in deep ocean waters. In open ocean surface waters dimethylmercury is lacking, maybe as a result of decomposition in the presence of light and an additional potential loss via evaporation from the water surface. Recent results suggest that low oxygen conditions are not necessary for the formation of dimethylmercury in the open oceans.

191. This contrasts with temperate lake waters where methylmercury is more commonly occurring than dimethylmercury. Studies in freshwater and estuarine environments have shown that methylation of mercury is primarily taking place under low oxygen conditions and mainly by sulphate-reducing bacteria. Here methylmercury is the product of methylation of ionic mercury. Figure 2.2 shows a diagram of the principal mercury reactions in the ocean.

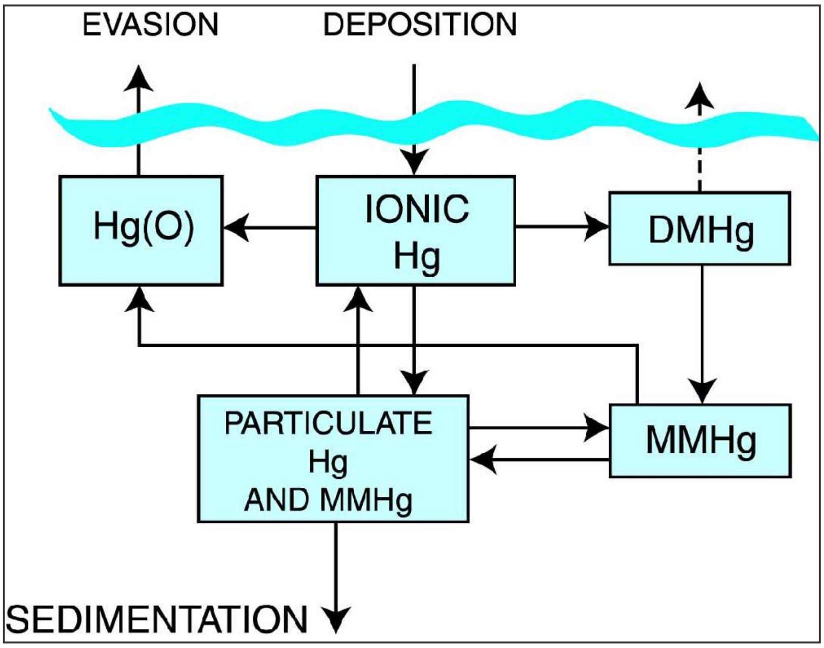


Figure 2.2 Dynamic interactions between the various mercury species in ocean waters (based on Mason and Fitzgerald, 1996). Hg(0) = elemental mercury, DMHg = dimethylmercury, MMHg = (mono)methylmercury.

2.4 Mercury species and transformation in soil

192. Soil conditions are typically favourable for the formation of inorganic and organic compounds, which form complexes with organic anions. This complexing behaviour controls to a large extent the mobility of mercury in soil. Much of the mercury in soil is bound to bulk organic matter and is susceptible to wash out in runoff only when attached to suspended soil or humus.

193. For these reasons mercury has a long retention time in soil and as a result, the mercury accumulated in soil may continue to be released to surface waters and other media for long periods of time, possibly hundreds years (Pirrone *et al*., 2001).

194. As described in chapter 5, findings in Sweden suggest that mercury has accumulated in organic forest soils to levels that may possibly reduce microbial activity, and thereby the base of the terrestrial food chain.

3 Toxicology

3.1 Overview

195. The toxicity of mercury depends on its chemical form, and thus symptoms and signs are rather different in exposure to elemental mercury, inorganic mercury compounds, or organic mercury compounds (notably alkylmercury compounds such as methylmercury and ethylmercury salts, and dimethylmercury). The sources of exposure are also markedly different for the different forms of mercury. For alkylmercury compounds, among which methylmercury is by far the most important, the major source of exposure is diet, especially fish and other seafood. For elemental mercury vapour, the most important source for the general population is dental amalgam, but exposure at work may in some situations exceed this by many times. For inorganic mercury compounds, diet is the most important source for the majority of people. However, for some segments of populations, use of skin-lightening creams and soaps that contain mercury and use of mercury for cultural/ritualistic purposes or in traditional medicine, can also result in substantial exposures to inorganic or elemental mercury.

196. While it is fully recognised that mercury and its compounds are highly toxic substances for which potential impacts should be considered carefully, there is ongoing debate on how toxic these substances, especially methylmercury, are. New findings during the last decade indicate that toxic effects may be taking place at lower concentrations than previously thought, and potentially larger parts of the global population may be affected. As the mechanisms of subtle toxic effects – and proving whether such effects are taking place – are extremely complex issues, a complete understanding has so far not been reached on this very important question.

Methylmercury

197. Of the organic mercury compounds, methylmercury occupies a special position in that large populations are exposed to it, and its toxicity is better characterized than that of other organic mercury compounds. Within the group of organic mercury compounds, alkylmercury compounds (especially ethylmercury and methylmercury) are thought to be rather similar as to toxicity (and also historical use as pesticides), while other organic mercury compounds, such as phenylmercury, resemble more inorganic mercury in their toxicity.

198. Methylmercury is a well-documented neurotoxicant, which may in particular cause adverse effects on the developing brain. Moreover, this compound readily passes both the placental barrier and the blood-brain barrier, therefore, exposures during pregnancy are of highest concern. Also, some studies suggest that even small increases in methylmercury exposures may cause adverse effects on the cardiovascular system, thereby leading to increased mortality. Given the importance of cardiovascular diseases worldwide, these findings, although yet to be confirmed, suggest that methylmercury exposures need close attention and additional follow-up. Moreover, methylmercury compounds are considered possibly carcinogenic to humans (group 2B) according to the International Agency for Research on Cancer (IARC, 1993), based on their overall evaluation.

Elemental mercury and inorganic mercury compounds

199. The main route of exposure for elemental mercury is by inhalation of the vapours. About 80 percent of inhaled vapours are absorbed by the lung tissues. This vapour also easily penetrates the blood-brain barrier and is a well-documented neurotoxicant. Intestinal absorption of elemental mercury is low. Elemental mercury can be oxidized in body tissues to the inorganic divalent form.

200. Neurological and behavioral disorders in humans have been observed following inhalation of elemental mercury vapour. Specific symptoms include tremors, emotional lability, insomnia, memory loss, neuromuscular changes, and headaches. In addition, there are effects on the kidney and thyroid.

High exposures have also resulted in death. With regard to carcinogenicity, the overall evaluation, according to IARC (1993), is that metallic mercury and inorganic mercury compounds are not classifiable as to carcinogenicity to humans (group 3). A critical effect on which risk assessment could be based is therefore the neurotoxic effects, for example the induction of tremor. The effects on the kidneys (the renal tubule) should also be considered; they are the key endpoint in exposure to inorganic mercury compounds. The effect may well be reversible, but as the exposure to the general population tends to be continuous, the effect may still be relevant.

Summary of effect levels

201. This chapter gives a brief presentation of the different adverse effects on human health from elemental (and inorganic) mercury, as well as methylmercury. To put the level of exposures for methylmercury in perspective, for the most widely accepted non-lethal adverse effect (neurodevelopmental effects), the United States (US) National Research Council (NRC, 2000) has estimated the benchmark dose (BMD) to be 58 µg/l total mercury in cord blood (or 10 µg/g total mercury in maternal hair) using data from the Faroe Islands study of human mercury exposures (Grandjean *et al.*, 1997). This BMD level is the lower 95% confidence limit for the exposure level that causes a doubling of a 5% prevalence of abnormal neurological performance (developmental delays in attention, verbal memory and language) in children exposed *in-utero* in the Faroe Islands study. These are the tissue levels estimated to result from an average daily intake of about 1 µg methylmercury per kg body weight per day (1 µg/kg body weight per day).

202. Other adverse effects have been seen in humans with less reliability or at much higher exposures. For methylmercury, effects have been seen on the adult nervous system, on cardiovascular disease, on cancer incidence and on genotoxicity. Also, effects have been reported on heart rate variability and blood pressure in 7 year-old children exposed prenatally, and on cardiovascular mortality in adults. For elemental mercury and inorganic mercury compounds, effects have been seen on: the excretion of low molecular weight proteins; on enzymes associated with thyroid function; on spontaneous abortion rates; genotoxicity; respiratory system; gastrointestinal (digestion) system; liver; immune system; and the skin. Several detailed evaluations of response as a function of exposure that have been conducted are reviewed in Chapter 4. As this report presents the toxicity of mercury in summary only, the reviews, which the presentation was based on, have not been checked in the original references for correct quoting during the preparation of this report.

Dietary considerations

203. Fish are an extremely important component of the human diet in many parts of the world and provide nutrients (such as protein, omega-3 fatty acids and others) that are not easily replaced. Mercury is a major threat to this food supply. Certainly, fish with low methylmercury levels are intrinsically more healthful for consumers than fish with higher levels of methylmercury, if all other factors are equal.

204. There is limited laboratory evidence suggesting that several dietary components might reduce (e.g. selenium, vitamin E, omega-3 fatty acids) or enhance (e.g. alcohol) mercury's toxicity for some endpoints. However, conclusions cannot be drawn from these data at this time.

Explanation of some of the medical terms used in this chapter

Albuminuria: Albuminuria is a form of proteinuria.

Anaemia: Condition in which the number of red blood cells per unit volume of blood is decreased from normal, resulting in decreased oxygen-carrying capacity of the blood.

Ataxia: Wobbliness. Incoordination and unsteadiness due to the brain's failure to regulate the body's posture and regulate the strength and direction of limb movements.

Atrophy of the brain: Shrinkage/loss/waste of the brain.

Cardiovascular effect: Effect on the circulatory system, comprising the heart and blood vessels.

Cerebellar ataxia: Ataxia (see above) due to disease of the cerebellum.

Cerebrovascular: Related to blood vessels of the brain.

Creatinine: A chemical waste molecule that is generated from muscle metabolism and excreted in the urine. The concentration of creatinine in serum is used as a measure for the function of the kidneys. Mercury concentrations measured in urine samples are sometimes presented on the basis of the creatinine contents in the same urine sample (µg mercury/g creatinine) – rather than per volume of urine (µg mercury/l) – in order to eliminate the variation in water contents in urine.

Cystic cavities and spongy foci: Tissue abnormality with holes and spongy areas.

Diastolic and systolic blood pressures: Diastolic blood pressure is the pressure when the heart is extending (dilating) and filled with blood. Systolic blood pressure when the heart is contracting. (A blood pressure of 140/90 means that the systolic blood pressure is 140 and the diastolic blood pressure 90).

Dysarthria: Speech that is characteristically slurred, slow, and difficult to produce (and understand). The person with dysarthria may also have problems controlling the pitch, loudness, rhythm and voice qualities of their speech.

Glomerular proteinuria: Proteinuria (see below) due to dysfunction of the renal glomerulus (unit of the kidney).

Glomerulonephritis: A variety of nephritis (inflammation of the kidney) characterised by inflammation of the capillary loops in the glomeruli of the kidney. (The glomerulus is a functional unit of the kidney).

Interstitial pneumonitis: A form of pneumonia which involves the interstitial tissues (connective tissue) of the lung.

Ischemia: Local anaemia due to obstruction of the blood supply (e.g., narrowing of the arteries).

Ischemic heart disease: Heart disease because of local anaemia.

Micronuclei in peripheral lymphocytes: Small cell nucleus in the peripheral white blood cells.

Neoplastic effect: Has the effect of creating new cells that grow autonomously. A neoplasm is new and abnormal growth of tissue, which can be benign or malign (cancerous).

Nephritic/nephrotic syndrome: A disease of the kidneys that results in inflammation of the glomerulus (the portion of the kidney that filters the blood). A type of nephritis that is characterised by low serum albumin, large amount of protein in the urine and swelling (oedema).

Nephritis: Inflammation of the kidneys.

Nephrosis: Non-inflammatory, non-neoplastic disease of the kidney.

Paresthesia: An abnormal sensation, such as burning, pricking, tingling, or numbness that appears to have no objective cause.

Peripheral neuropathy: Degeneration of peripheral nerves (peripheral nerves are all nerves except the brain and the spinal cord).

Pneumonitis: Inflammation of the lungs secondary to viral or bacterial infection.

Proteinuria: More protein in the urine than normal (normal excretion is 150mg protein daily).

Renal tubule: Small structures in the kidney that filter the blood and produce the urine.

Stomatitis: Infection of the mucous membrane (the inside) of the mouth.

Tachycardia: A rapid heart rate, usually defined as greater than 100 beats per minute.

Tubular proteinuria: More protein in the urine than normal due to dysfunction of the renal tubules.

3.2 Methylmercury

205. While mainly focusing on methylmercury, this section also gives a few remarks on other organic mercury substances.

206. The compound dealt with most extensively in toxicological research in recent years is methylmercury. Like other alkylmercury compounds, the toxicity of methylmercury is much higher than that of inorganic mercury. Methylmercury is a potent neuro-toxin, hence human exposure to methylmercury is clearly unwelcome and should be regarded with concern. It is present worldwide in fish and marine mammals consumed by humans. Methylmercury is formed naturally (from anthropogenic and naturally released mercury) by biological activity in aquatic environments, and it is bio-magnified in the food chain, resulting in much higher concentrations in higher predatory fish and mammals than in water and lower organisms. Most of the total mercury concentrations in fish are in the form of methylmercury (close to 100 percent for older fish). Methylmercury has also been used deliberately as a pesticide/biocide (e.g. seed grain treatment), and this use gave rise to severe historical poisoning incidents in Iraq before 1960 and again in the early 1970's (US EPA, 1997).

207. Consumption of contaminated fish and marine mammals is the most important source of human exposure to methylmercury (WHO/IPCS, 1990; US EPA, 1997). The highest concentrations are found in large predatory fish like shark, king mackeral, swordfish and some large tuna (as opposed to the smaller tuna usually used for canned tuna), as well as in some freshwater fish like pike, walleye, bass, perch, and eels, and in mammals like seals and whales. Due to long-range atmospheric emission transport and ocean currents, methylmercury is also present in the environment far away from local or regional mercury sources. This implies that population groups particularly dependent on – or accustomed to – marine diets, such as the Inuits of the Arctic, as well as marine and freshwater fish-dependent populations anywhere else on the globe, are particularly at risk due to methylmercury exposure.

208. Methylmercury is highly toxic, and the nervous system is its principal target tissue. In adults, the earliest effects are non-specific symptoms such as paresthesia, malaise, and blurred vision; with increasing exposure, signs appear such as concentric constriction of the visual field, deafness, dysarthria, ataxia, and ultimately coma and death (Harada, 1995). The developing central nervous system is more sensitive to methylmercury than the adult. In infants exposed to high levels of methylmercury during pregnancy, the clinical picture may be indistinguishable from cerebral palsy caused by other factors, the main pattern being microcephaly, hyperreflexia, and gross motor and mental impairment, sometimes associated with blindness or deafness (Harada, 1995; Takeuchi and Eto, 1999). In milder cases, the effects may only become apparent later during the development as psychomotor and mental impairment and persistent pathological reflexes (WHO/IPCS, 1990; NRC, 2000). Studies from one population exposed to methylmercury from fish also suggest an association with increased incidence of cardiovascular system diseases (Salonen *et al.*, 1995, Rissanen *et al.*, 2000). From research on animals there is evidence of genotoxicity and effects on the immune system and the reproductive system.

209. Substantial parts of the descriptive text in this section were based on Pirrone *et al.* (2001) and to a lesser extent the submission from the Nordic Council of Ministers (sub84gov). Pirrone *et al.* (2001), mention that their presentation was largely based on previous reviews by WHO (WHO/IPCS 1990; 1991), IARC (IARC, 1993) and the US EPA (US EPA 1997; 2001b).

3.2.1 Neurological effects

210. In the most recent authorative evaluations of the toxicological effects of methylmercury (WHO/IPCS, 1990; NRC, 2000) it was concluded that the effects on the developing nervous system in unborn and newborn children are the most sensitive, well-documented effects judged from the evidence from human and animal studies. Such effects can take place even at exposure levels where the mother (through whom the children receive the mercury) remains healthy or suffers only minor symptoms due to mercury exposure (WHO/IPCS, 1990; Davis *et al.*, 1994, as cited by Pirrone *et al.*, 2001).

211. Methylmercury in our food is rapidly absorbed in the gastrointestinal tract and readily enters the brain. From the methylmercury poisoning episodes in Japan and Iraq it was known that the most severe effects take place in the development of the brain and nervous system of the unborn child (the fetus), but also severe effects on adults were observed. A series of large epidemiological studies have recently provided evidence that methylmercury in pregnant women's marine diets – even at low mercury concentrations (about 1/10 - 1/5 of observed effect levels on adults) – appears to have subtle, persistent effects on the children's mental development as observed at about the start of the school age (so-called cognitive deficits; NRC, 2000).

212. The Faroe Islands population was exposed to methylmercury mainly from pilot whale meat with relatively high concentration of methylmercury, around 2 mg/kg (US EPA, 2001b). The study of about 900 Faroese children showed that prenatal exposure to methylmercury resulted in neuropsychological deficits at 7 years of age (Grandjean *et al*., 1997). The brain functions most vulnerable seem to be attention, memory, and language, while motor speed, visiospatial function, and executive function showed less robust decrements at increased mercury exposures. The mercury concentration in cord blood appeared to be the best risk indicator for the adverse effects, which were apparently only slightly affected by a large number of covariates examined. Special concern was expressed with respect to the impact of PCBs, which was present in the diet (in whale blubber) of these Faroese mothers. The results were roughly unchanged, however, when PCB levels were taken into account, and increased prenatal exposure to methylmercury appeared to enhance PCB toxicity (Grandjean et al., 2001). Developmental delays were significantly associated the methylmercury exposures, even if excluding the children whose mothers had hair mercury concentrations above 10 µg/g. Within the low exposure range, each doubling of the prenatal methylmercury exposure level was associated with a developmental delay of 1-2 months. On an individual basis the effects at these dose levels may not seem severe, but they may have severe implications on a population basis.

213. To put the level of exposures for methylmercury in perspective, for the most widely accepted non-lethal effect (neurodevelopmental effects), the benchmark dose (BMD) level is calculated to be 58 µg/l total mercury in cord blood (or 10 µg/g total mercury in maternal hair) using data from the Faroe Islands study of human mercury exposures (NRC, 2000; Budtz-Jorgensen *et al*., 2000). This BMD level is the lower 95 percent confidence limit for the exposure level that causes a doubling of a 5 percent prevalence of abnormal neurological performance (developmental delays in attention, verbal memory and language) in children exposed *in-utero* in the Faroe Islands study. This dose level is estimated from actual test observations and analysis hereof, involving a number of scientifically based choices including statistic model and specific effect/test of effect used for evaluation. The 58 µg/l total mercury in cord blood and 10 µg/g total mercury in maternal hair are the tissue levels estimated to result from an average daily intake of about 1 microgram methylmercury per kilogram body weight per day (1 µg/kg body weight per day). By using an uncertainty factor of 10, this BMD level has been used to estimate safe exposure levels for humans (US EPA, 2001b; NRC, 2000; Pirrone *et al.,* 2001).

214. Another prospective study is ongoing in the Seychelles islands, where the methylmercury exposures are of similar extent. The fish consumption of pregnant women in the Seychelles is high, typically 10-15 meals per week (Shamlaye, 1995), while the mercury concentrations in the ocean fish consumed is lower (than the mercury concentrations in the pilot whale meat consumed by the Faroe Islands population), with a mean of 0.2-0.3 mg/kg (Cernichiari *et al.*, 1995). No effects on developmental tests up to 5.5 years of age were found to be associated with methylmercury exposure, as measured by hair-mercury in the pregnant mothers (Davidson *et al.*, 1998; Crump *et al.*, 2000; Myers *et al.*, 2000; Axtell *et al.*, 2000; Palumbo *et al.*, 2000). The main longitudinal study was started in 1989-1990 and comprised about 700 mother-child pairs. Maternal hair (mean about 7 µg/g) and child hair, but not cord-blood levels were used as markers of methylmercury exposure in this study. A reanalysis using raw scores rather than age standardized scores showed similar results. (Davidson *et al.*, 2001)

215. In addition, there is a study from New Zealand, suggesting an effect on the mental development of children at the age of 4 and 6-7 years. In a high-exposure group the average maternal hair-mercury was about 9 µg/g, and control groups were selected with lower exposure levels. In total, about 200 chil-

dren were examined at 6-7 years of age and a negative association was found between maternal hair-mercury and neuropsychological development of the children. Although carried out a decade earlier than the Seychelles and Faroe Islands studies (published as reports from the Swedish Environmental Protection Agency (Kjellstrom *et al.,* 1986; 1989)), inclusion of the findings from this study was considered appropriate by the US EPA in their recent assessment (US EPA, 2001b) given the similarities in study design and endpoints considered, and following a later analysis of data by Crump using a "benchmark dose" approach (Crump *et al.*, 1998).

216. Some cross-sectional studies using neuropsychological testing of older children in different settings (such as in the Amazonas and on the Madeira island), also found significant associations with mercury exposure (for a review, see US EPA, 2001b). As the relationship between mercury concentrations found in maternal hair, as well as in umbilical cord blood, and mercury concentrations in human diet is relatively well described (with some biological variation), it is possible to estimate corresponding levels of methylmercury doses in human diet, deemed to be safe. See section 4.2.1 on the use of such a risk evaluation tool.

217. The original epidemiological report of methylmercury poisoning involved 628 human cases that occurred in Minamata, Japan, between 1953 and 1960. The overall prevalence rate for the Minamata region for neurologic and mental disorders was 59 percent. Among this group 78 deaths occurred, and hair concentrations of mercury ranged from 50–700 µg/g. The most common clinical signs observed in adults were paresthesia, ataxia, sensory disturbances, tremors, impairment of hearing and difficulty in walking. Examination of the brains of severely affected patients that died revealed marked atrophy of the brain (55 percent normal volume and weight) with cystic cavities and spongy foci. Microscopically, entire regions were devoid of neurons, granular cells in the cerebellum, Golgi cells and Purkinje cells. Extensive investigations of congenital Minamata disease (children of exposed women) were undertaken, and 20 cases that occurred over a 4-year period were documented. In all instances the congenital cases showed a higher incidence of symptoms than did the cases wherein exposure occurred as an adult. Severe disturbances of nervous function were described, and the affected offspring were very late in reaching developmental milestones. Hair concentrations of mercury in affected infants ranged from 10 to 100 µg/g (Harada, 1995; 1997; Tsubaki and Takahashi, 1986; WHO/IPCS, 1990). In addition, later studies of patients with Minamata disease reported increased pain thresholds (an adverse effect) in the body and distal extremities (Yoshida *et al*., 1992).

Symptoms and health effects of Minamata disease

The symptoms of Minamata disease include:

- sensory disorders in the four extremities (loss of sensation in the hands and feet);
- ataxia (difficulty in coordinating movement of hands and feet);
- narrowing of the field of vision;
- hearing impairment;
- impairment of faculties for maintaining balance;
- speech impediments;
- trembling of hands and feet; and
- disorders of the ocular movement.

In very severe cases, victims fall into a state of madness, lose consciousness and may even die. In relatively mild cases, the condition is barely distinguishable from other ailments such as headache, chronic fatigue and generalized inability to distinguish taste and smell.

When the first outbreaks of Minamata disease occurred, most patients exhibited a full set of severe symptoms. In 16 cases, the patient died within 6 months of the onset of symptoms, and in 1965 the mortality was 44.3 percent. Since then a large number of incomplete or mild cases, displaying an incomplete set of symptoms, have also been identified. (Minamata City, 2000)

Methylmercury poisoning in Minamata Bay, Japan

During the 1960/70's, the Minamata Bay mercury pollution problem received world-wide media attention, opening the world's eyes to the negative health effects of methylmercury and contributing to raising public awareness of the importance of environmental protection.

More than forty years ago, Minamata Bay in Japan was seriously polluted by wastewater containing methylmercury, formed as a by-product in the acetaldehyde synthesizing process of the local acetaldehyde chemical plant; 70-150 metric tons or more of mercury, mixed in the effluents from the factory, were discharged over a number of years into the Bay. The pollution affected the people of Minamata in the form of methylmercury poisoning, referred to as "Minamata disease", causing damage to the central nervous system in people eating large quantities of contaminated fish and shellfish from Minamata Bay. In addition, Congenital Minamata disease occurred, in which victims were born with a condition resembling cerebral palsy, caused by methylmercury poisoning of the fetus via the placenta when the mother consumed contaminated seafood during pregnancy. The disease, which was officially recognized on 1 May 1956, severely affected the local community and was a great burden to the city. Many people lost their lives or suffered from physical deformities and have had to live with the physical and emotional pain of "Minamata Disease" since.

After the cause of the disease was finally confirmed, a number of measures were gradually implemented to deal with the problems arising from the mercury pollution, ranging from regulation of the factory effluent, voluntary restrictions on harvesting of fish and shellfish from the Bay, installation of dividing nets in order to enclose the mouth of the Bay and prevent the spread of contaminated fish, to dredging of mercury-containing sediments in the Bay and appropriate deposit to contain the mercury-contaminated sludge. Finally, in October 1997, the dividing nets that had closed off the bay for 23 years were removed. After several studies confirming that mercury levels in fish were below regulatory levels and had remained so for three years, Minamata Bay was reopened as a general fishing zone and the Minamata Fisheries Co-op recommenced harvesting for the fish market (Minamata City, 2000).

The National Institute for Minamata Disease was formed to investigate the impacts of mercury contamination, and has contributed substantially to the knowledge of mercury toxicology and exposure both nationally and in other regions of the world since then.

The Ministry of Environment of Japan, in its report "Our Intensive Efforts to Overcome the Tragic History of Minamata Disease (JME, 1997)" concludes:
"From the incidence of Minamata Disease, Japan has learned a very important lesson on how activities that place priority on the economy, but lack consideration for the environment can cause grave damage to health and environment, and how it is difficult to recover from this damage later on. From the purely economic standpoint, too, a large amount of cost and a great deal of time are required to deal with such damages, and, when we compare these costs incurred vs. the cost of the measures that could have prevented the pollution, allowing such pollution is certainly not an economically advisable option. In our country, with the experience of suffering from disastrous damage by pollution including the Minamata Disease as a turning point, measures to protect the environment have made dramatic progress. But the sacrifices incurred on the way were truly huge, indeed. We sincerely hope that Japan's experience can be utilized as a vital lesson by other countries, that consideration is paid to the importance of the environment, and that pollution will be prevented without ever undergoing this kind of tragic pollution-related damage."

218. Several neurological signs and symptoms are among the cardinal features of high-dose exposures to methylmercury in adults. As no specific medical test is available to confirm the diagnosis of Minamata disease, cases were identified on the basis of a characteristic combination of symptoms (Harada, 1997; Uchino *et al*., 1995). These included peripheral neuropathy, dysarthria, tremor, cerebellar ataxia, gait disturbance, visual-field constriction and disturbed ocular movements, hearing loss, disturbance of equilibrium, and subjective symptoms such as headache, muscle and joint pain, forgetfulness, and fatigue. Based on the assessment conducted by WHO/IPCS (1990), paresthesias in five percent of the adult population were judged to occur at hair mercury concentrations above 50 µg/g or blood mercury concentrations above 200 µg/l (WHO/IPCS, 1990). Later research provides some evidence of effects at lower concentrations on adults, see Lebel *et al*. (1998) below.

219. The predominant symptom noted in adults in the 1971 Iraqi poisoning incident was paresthesia, and it usually occurred after a latent period of from 16 to 38 days. In adults symptoms were dose-dependent, and among the more severely affected individuals ataxia, blurred vision, slurred speech and hearing difficulties were observed (Bakir *et al.*, 1973). Signs noted in the infants exposed during fetal development included cerebral palsy, altered muscle tone and deep tendon reflexes, as well as delayed developmental milestones. The mothers experienced paresthesia and other sensory disturbances but at higher doses than those associated with their children exposed *in utero* (during mothers pregnancy; Bakir *et al.*, 1973; WHO/IPCS, 1990; Al-Mufti *et al.*, 1976).

Mercury poisoning incidents in Iraq

Methyl- and ethylmercury poisonings occurred in Iraq following consumption of seed grain that had been treated with fungicides containing these alkylmercury compounds. The first outbreaks were caused by ethylmercury, and occurred in 1956 and 1959-1960, and about 1000 people were adversely affected. The second outbreak was caused by methylmercury and occurred in 1972. The number of people admitted to the hospital from the second outbreak with symptoms of poisoning has been estimated to be approximately 6,500, with 459 fatalities reported. Imported mercury-treated seed grains arrived after the planting season and were subsequently used as grain to make into flour that was baked into bread. Unlike the long-term exposures in Japan, the epidemic of methylmercury poisoning in Iraq was short in duration, but the magnitude of the exposure was high. Because many of the people exposed to methylmercury in this way lived in small villages in very rural areas (and some were nomads), the total number of people exposed to these mercury-contaminated seed grains is not known.

220. Lebel *et al*. (1998) found that abnormal performance on the Branches Alternate Movement Task (BAMT) was significantly associated with all measures of mercury exposure in adults from an Amazonian village, and abnormal visual fields were associated with mean and peak hair mercury concentrations. The authors state that the dose-related decrements in visual and motor functions were associated with hair mercury concentrations below 50 µg/g, a range in which clinical signs of mercury intoxication are not apparent. [1]

3.2.2 Cancer (neoplastic effects)

221. Studies were conducted on causes of death in populations in Minamata, Japan, with high exposures to methylmercury. The only clear indication of an increased cancer risk was in the most informative of these studies, in which excess mortality from cancer of the liver and of the oesophagus was found in the area with the highest exposure, together with an increased risk for chronic liver disease and cirrhosis. Consumption of alcoholic beverages was known to be higher than average in the area (IARC, 1993).

222. A cohort study of individuals in Sweden with a licence for seed disinfection with mercury compounds and other agents found no excess of brain cancer. Of the three Swedish case-control studies on exposure to mercury seed dressings and soft-tissue sarcomas, only one showed an odds ratio above unity. In all three studies the confidence intervals included unity. For malignant lymphomas, there was a slightly but nonsignificantly elevated odds ratio for exposure to mercury seed dressings, but other exposures had higher odds ratios and consequently, potential confounding factors (IARC, 1993).

223. Methylmercury chloride caused renal tumours in several studies in mice exposed through the diet, but not in rats. IARC judged that there is sufficient evidence for carcinogenicity of methylmercury

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[1] The USA, in their comments to the first draft of this report (comm-24-gov), comment that in the Amazonian population, concurrent or previous exposure to metallic mercury vapour could not be entirely ruled-out, and there were other problems with nutrition, parasitism, and possible nutritional deficiencies in that population. Therefore, according to the US comments, other factors may have contributed to the neurological deficits reported; and the hair mercury concentration may thus be an inappropriate index for full attribution of the observed neurotoxicity.

chloride in experimental animals. In its overall evaluation for methylmercury compounds, where other relevant data were taken into consideration when making the overall evaluation, it concluded that methylmercury compounds are possibly carcinogenic to humans (group 2B) (IARC, 1993).

3.2.3 Renal effects (kidneys)

224. Renal toxicity has rarely been reported following human exposure to organic forms of mercury. The only evidence of a renal effect following ingestion of mercury-contaminated fish comes from a death-certificate review conducted by Tamashiro *et al*. (1986). They evaluated causes of death among residents of a small area of Minamata City that had the highest prevalence of Minamata disease using age-specific rates for the entire city as a standard. Between 1970 and 1981, the number of deaths attributed to nephritic diseases was higher than expected among women who resided in that region (mortality rate "SMR", 2.77; 95% CI, 1.02 – 6.02), but was within the expected range (mortality rate "SMR", 0.80; 95% CI, 0.17 – 2.36) among men who resided in this region.

3.2.4 Cardiovascular effects (heart and blood system)

225. Jalili and Abbasi (1961) described ECG (heart function) abnormalities in severely poisoned patients hospitalized during the Iraqi grain ethylmercury poisoning epidemic, and similar findings were reported in four family members who consumed ethylmercury-contaminated pork (Cinca *et al*., 1979). Salonen *et al*. (1995) compared dietary intake of fish and mercury concentrations in hair and urine with the prevalence of acute myocardial infarction (AMI) and death from coronary heart disease or cardiovascular disease in a cohort of 1,833 Finnish men. Dietary mercury intake ranged from 1.1 to 95.3 µg per day (mean 7.6 µg per day). Over a 7-year observation period, men in the highest tertile (at or more than 2 µg/g) of hair mercury content had a two-fold higher risk (1.2 – 3.1) of AMI than men in the two lowest tertiles. A later follow-up (Rissanen *et al*., 2000) showed a protective effect of omega-3 fatty acids with respect to acute coronary disease, which was, however, less evident in those with hair mercury at or above 2 µg/g. The authors concluded that a high mercury content in fish could reduce the protective effect of these fatty acids. A recent study by Sørensen *et al*. (1999) showed an association between prenatal exposure to methylmercury and cardiovascular function at age 7 in the children from the Faroe Islands, though this study was based on a single measurement per subject of blood pressure, with accompanying high uncertainty. Diastolic and systolic blood pressures increased by 13.9 and 14.6 mmHg, respectively, as cord-blood mercury concentrations rose from 1 to 10 µg/l. In boys, heart-rate variability, a marker of cardiac autonomic control, decreased by 47 percent as cord-blood mercury concentrations increased from 1 to 10 µg/l.

226. These studies suggest that even small increases in methylmercury exposures may cause adverse effects on the cardiovascular system, thereby leading to increased mortality. Given the importance of cardiovascular diseases worldwide, these findings need close attention and additional follow-up.

3.2.5 Genotoxicity

227. Skervfing (1974) found limited support for an association between chromosomal aberations and mercury in red blood cells in subjects consuming large amounts of contaminated freshwater fish. Wulf *et al*. (1986) reported an increased prevalence of sister chromatid exchange in humans who ate mercury-contaminated seal meat. However, information on smoking status and exposure to other heavy metals was not provided for those individuals, making interpretation of the study difficult. No increase in the frequency of sister chromatid exchange or numerical chromosomal alterations was detected in 16 subjects who ate fish caught from a methylmercury contaminated area in Colombia as compared to 14 controls (Monsalve and Chiappe, 1987). More recently, Franchi *et al*. (1994) reported a correlation between the prevalence of micronuclei in peripheral lymphocytes and blood mercury concentrations in a population of fishermen who had eaten mercury-contaminated seafood.

3.3 Elemental and inorganic mercury

228. While many sources of elemental mercury exist, a major exposure route of elemental mercury is dental amalgam. Other exposures to this mercury species are considered in general decline in Europe and most likely also in many other OECD countries. In these regions, methylmercury is considered the remaining exposure of most importance to humans. The national submissions to UNEP for this assessment indicate however that the exposures to elemental and inorganic mercury from local pollution, occupational exposure, certain cultural and ritualistic practices, and some traditional medicines may vary considerably between countries and regions in the world, and that these exposures are significant in some areas.

229. The following presentation of toxic effects of elemental and inorganic mercury is based on a presentation prepared by Pirrone *et al.* (2001), and was edited slightly for this report. Pirrone *et al.* (2001), mention that their presentation was largely based on previous reviews by WHO (WHO/IPCS, 1990; 1991), IARC (IARC, 1993), and US EPA (US EPA, 1997; 2001b). Also, some information was obtained from the recent IPCS report (WHO/IPCS, 2002).

230. Signs and symptoms observed in mercury vapour poisoning differ depending on the level and duration of exposure. Most studies have been performed in occupationally exposed subjects, but there are also some data from accidents in the general population, and on low-level exposure from dental amalgams. The latter subject has been widely discussed and reviewed (US Public Health Service, 1993; Clarkson, 2002; WHO/IPCS, 2002).

3.3.1 Neurological effects

231. As reviewed by the US EPA (1997), the reports from accidental exposures to high concentrations of mercury vapours (Aronow *et al*., 1990; Fagala and Wigg, 1992; Taueg *et al*., 1992), as well as studies of populations chronically exposed to potentially high concentrations (Ehrenberg *et al*., 1991; Roels *et al*., 1982; Sexton *et al*., 1978) have shown effects on a wide variety of cognitive, sensory, personality and motor functions. In general, symptoms have been observed to subside after removal from exposure. However, persistent effects (tremor, cognitive deficits) have been observed in occupationally exposed subjects 10-30 years after cessation of exposure (Albers *et al*., 1998; Kishi *et al*., 1993; Mathiesen *et al*., 1999; Letz *et al*., 2000).

232. Studies of workers exposed to elemental mercury vapour have reported a clear increase in symptoms of disfunction of the central nervous system at exposure levels greater than 0.1 mg/m^3 (Smith *et al*., 1970) and clear symptoms of mercury poisoning at levels resulting in urinary mercury greater than 300 µg in a 24-hour urine sample (Bidstrup *et al*., 1951). Several studies, however, have shown evidence of neurotoxicity at approximately 2- to 4-fold lower concentrations. Self-reported memory disturbances, sleep disorders, anger, fatigue, and/or hand tremors were increased in workers chronically exposed to an estimated air concentration of 0.025 mg/m^3 (approximately equal to urinary and blood mercury levels of about 25 µg/g and 10 µg/l) (Langworth *et al*., 1992), but not in a recent study with somewhat lower exposure levels, urinary mercury 10-15 µg/g (Ellingsen *et al*., 2001).

233. Objective measures of cognitive and/or motor function in exposed populations have shown significant differences from unexposed controls (Ehrenberg *et al*., 1991; Liang *et al*., 1993; Roels *et al*., 1982). In the study by Langworth *et al.* (1992), there were, however, no objective findings in neuropsychological tests or tremor recordings. This was also mainly the case in the study by Ellingsen *et al.* (2001), although there were possibly some exposure-related effects. Tremor was reported at long-term exposure to relatively low concentrations of mercury vapour (Fawer *et al*., 1983; Chapman *et al*., 1990), and mild tremor may constitute an early adverse effect (Biernat *et al*., 1999; Netterstrøm *et al*., 1996). Several studies failed, however, to show an increase of tremor at low-level exposure (Roels *et al*., 1989; Langworth *et al*., 1992; Ellingsen *et al*., 2001).

234. In a recent assessment of all studies on the exposure-response relationship between inhaled mercury vapour and adverse health effects, IPCS concluded that several studies consistently demon-

strate subtle effects on the central nervous system in long-term occupational exposures to mercury vapour at exposure levels of approximately 20 µg/m^3 or higher (WHO/IPCS, 2002).

3.3.2 Renal effects (kidneys)

235. The kidney is, together with the central nervous system, a critical organ for exposure to mercury vapour. Elemental mercury can be oxidized in body tissues to the inorganic divalent form. The kidney accumulates this inorganic mercury to a larger extent than most other tissue with concentrations in occupationally unexposed groups typically of 0.1 – 0.3 µg/g (Drasch *et al.*, 1996; Barregard *et al.*, 1999; Hac *et al.*, 2000; Falnoga *et al.*, 2000). The critical kidney mercury concentration is not known, but levels in subjects with ongoing occupationally exposure may be about 25 µg/g (Kazantzis *et al.*, 1962; Borjesson *et al.*, 1995; Barregard *et al.*, 1999).

236. High exposure may cause (immune-complex mediated) glomerulonephritis with proteinuria and nephritic syndrome. This has been shown at occupational exposures (Kazantzis, 1962; Tubbs *et al.*, 1982), as well as after use of mercury-containing ointment or skin-lightening creams (Becker *et al.*, 1962; Kibukamusoke *et al.*, 1974), but the reported cases are relatively few. Therefore, a specific genetic susceptibility is probably needed for a frank nephritis to develop. For a review, see Eneström and Hultman (1995).

237. More common at high exposure is proteinuria, glomerular (albumin) as well as tubular (low molecular weight proteins). Albuminuria is, however, generally not seen at exposure levels resulting in urinary mercury below 100 µg/g creatinine (Buchet *et al.*, 1980; Roels *et al.*, 1982; 1989; Langworth *et al.*, 1992; Barregard *et al.*, 1997; Ellingsen *et al.*, 2000).

238. Effects on the renal tubules, as demonstrated by increased excretion of low molecular proteins, have been shown at low-level exposure, and may constitute the earliest biological effect. This effect was previously shown at occupational exposure with urinary mercury of about 35 µg/g creatinine, equivalent to long-term exposure to air levels of 25-30 µg/m^3 (Barregard *et al.*, 1988; Langworth *et al.*, 1992; Cardenas *et al.*, 1993). In a recent report by Ellingsen *et al.* (2000), such an effect was also shown in workers with urinary mercury of about 10 µg/g creatinine. Ongoing research (Wastensson G, personal communication, 2001, as quoted by Pirrone *et al.*, 2001) appears to support the finding of low-level effects in Swedish chlor-alkali workers at levels in the range of 5 µg/g creatinine, which is only slightly higher than that found in the general population. On the other hand, the possible long-term implications of tubular proteinuria are still unclear (Jarup *et al.*, 1998). For example, Ellingsen *et al.* (1993a) have suggested that some renal effects may be reversible after a long enough period of time, and Frumkin *et al.* (2001) have concluded from their research that "no strong associations were demonstrated with neurological or renal function or with porphyrin excretion."

239. Among male European mercury miners an increased mortality was observed from nephritis and nephrosis (mortality rate "SMR" 1.55, 95 % CI 1.13-2.06) (Boffetta *et al.*, 2001), whereas this was not shown among chlor-alkali workers (Barregard *et al.*, 1990; Ellingsen *et al.*, 1993).

240. The IPCS recently concluded (WHO/IPCS, 2002), based on existing studies, that adverse effects on the kidney usually occur at exposures higher than those inducing neurophysiological effects. Also, although a large number of serious and even fatal intoxications (often suicides or suicide attempts) have been described after ingestion of inorganic mercury compounds, data from humans does not allow identification of lowest harmful or non-adverse exposure levels, especially in long-term exposure. From studies on experimental animals, a No-Adverse-Effect Level (NOAEL) of 0.23 mg/kg per day was identified (US ATSDR, 1999; WHO/IPCS, 2002).

3.3.3 Cancer (neoplastic effects)

241. Data on the carcinogenicity of metallic mercury and its inorganic compounds mainly come from studies on cancer occurrence in occupational populations, including dentists, nuclear weapon

manufacturers, chlor-alkali workers and miners. Previous data are summarized in reviews (IARC, 1993; Boffetta *et al.*, 1993).

242. In 1993, IARC evaluated metallic mercury and inorganic mercury compounds and found that there was inadequate evidence in experimental animals for carcinogenicity of metallic mercury and limited evidence in experimental animals for carcinogenicity of mercuric chloride. In its overall evaluation, it concluded that metallic mercury and inorganic mercury compounds are not classifiable (group 3) with respect to carcinogenicity in humans (IARC, 1993).

243. Citing a number of studies of occupational mercury exposure, including studies done after the IARC evaluation in 1993, Pirrone *et al.* (2001) concludes that lung cancer is the only cancer form, which seems to be consistently increased among various groups of workers exposed to metallic and inorganic mercury. The main difficulty in the interpretation of the data on lung cancer is the possible co-exposure to other lung carcinogens, in particular arsenic (in the fur industry), radon and silica (among miners). An additional limitation is the almost universal lack of data on tobacco smoking. The fact that no increase was found in a large group of European mercury miners not exposed to quartz (Boffetta *et al.*, 1998) argues against the hypothesis that mercury vapour may cause lung cancer. There is no suggestion of a consistent increase of any other neoplasm, including brain and kidney cancers, in these populations.

3.3.4 Respiratory effects

244. Respiratory toxicity in humans following exposure to elemental mercury vapours has been characterized by pulmonary edema and congestion, coughing, interstitial pneumonitis and respiratory failure (Bluhm *et al.*, 1992; Taueg *et al.*, 1992; WHO/IPCS, 1991). Barregard *et al.* (1990) and Ellingsen *et al.* (1993) found no associations between mortality from respiratory disease and mercury exposure among workers exposed to mercury in the chlor-alkali industry, although the power of the studies were low. Merler *et al.* (1994) found no excess mortality of respiratory disease in men (mortality rate “SMR”, 0.67; 95% CI, 0.35 – 1.14) exposed to mercury in the fur hat industry. This was also true for mercury miners, except for pneumoconiosis (Boffetta *et al.*, 2001).

3.3.5 Cardiovascular effects (heart and blood system)

245. Signs of cardiovascular toxicity in humans after acute exposure to elemental mercury include tachycardia, elevated blood pressure and heart palpitations (Bluhm *et al.*, 1992; Snodgrass *et al.*, 1981; Soni *et al.*, 1992, Wossmann *et al.*, 1999). Intermediate-duration exposure to elemental mercury vapours produced similar effects (i.e., tachycardia and elevated blood pressure) (Fagala and Wigg, 1992; Foulds *et al.*, 1987). Piikivi (1989) demonstrated a positive correlation between heart palpitations and urinary mercury concentrations in workers from a chlor-alkali plant but also “found only a tendency for a subtle reduction of cardiovascular reflex responses and a slight increase of subjective symptoms, but no significant autonomic dysfunction associated with the low levels of exposure.” Nevertheless, it is unclear from the available scientific literature whether the effects on cardiovascular function are due to direct cardiac toxicity or to indirect toxicity (e.g., due to effects on neural control of cardiac function) of elemental mercury. Barregard *et al.* (1990) showed that Swedish chlor-alkali workers had increased mortality due to ischemic heart disease and cerebrovascular disease. However, there were no such findings in Norwegian chlor-alkali workers (Ellingsen *et al.*, 1993a). Nonetheless, the IPCS (2003) and US ATSDR (1999) have recently reported that acute inhalation exposure to high concentrations of elemental mercury vapour from the heating of elemental/inorganic mercury resulted in increased blood pressure and palpitations. Exposures of longer durations due to spills or occupational exposures have also been reported to result in increased blood pressure and increased heart rate (WHO/IPCS, 2002; US ATSDR, 1999).

246. Among European mercury miners, increased mortality from hypertension (SR 1.46, 95 % CI 1.08-1.93) and from heart diseases (other than ischemic disease) have been reported (mortality rate “SMR”, 1.36, 95 % CI 1.20-1.53), and these effects increased with time since first employment and

with estimated cumulative mercury exposure. But, findings were not consistent among countries. Also, no increase was shown for ischemic heart disease or cerebrovascular diseases (Boffetta *et al*., 2001).

247. Statistically significant increases of approximately 5 mmHg in both systolic and diastolic blood pressure were found in 50 volunteers with dental amalgam when compared to an age- and sex-matched control group (average age approximately 22 years) without mercury amalgam fillings. Potential confounding differences between the two groups, such as life-style and body mass, were not discussed. Significantly decreased hemoglobin and hematocrit, and increased mean corpuscular hemoglobin concentration were also found compared to controls without dental amalgams (Siblerud, 1990, as cited in WHO/IPCS, 2002).

3.3.6 Gastrointestinal (digestive system) and hepatic (liver) effects

248. The most common sign of frank mercury poisoning is stomatitis, which is usually reported following acute, high concentration exposure to elemental mercury vapours (Bluhm *et al*., 1992; Snodgrass *et al*., 1981). Other commonly reported gastrointestinal effects include nausea, vomiting, diarrhea and abdominal cramps (Bluhm *et al*., 1992; Lilis *et al*., 1985; Sexton *et al*., 1978; Snodgrass *et al*., 1981; Vroom and Greer, 1972). However, no increased mortality from the digestive system was observed in European mercury miners (Boffetta *et al*., 2001).

3.3.7 Effects on the thyroid gland

249. The thyroid may accumulate mercury with continued exposure to elemental mercury (Kosta *et al*., 1975; WHO/IPCS, 1991; Falnoga *et al*., 2000). It has been shown that moderate occupational exposure affects a particular enzyme system in the thyroid at urinary mercury levels of 15-30 µg/g creatinine – the same levels as those associated with reports of minor effects on the central nervous system and the kidneys (Barregard *et al*., 1994; Ellingsen *et al*., 2000). A recent study (Ellingsen *et al*., 2000) compared thyroid function in 47 chlor-alkali workers exposed to mercury vapours for an average of 13.3 years with 47 “referents.” The median serum concentration of reverse triiodothyronine (T3) was statistically significantly higher in the exposed group compared to the referents. Also, the free thyroxine (T4)/free T3 ratio was higher in the highest exposed subgroups compared with referents. The enzyme deiodinase responsible for the deiodination of thyroxine (T4) to triiodothyronine (T3), a seleno-enzyme, seems to be affected. However, Ellingsen *et al.* (2000) also reported that the “overall function of the thyroid gland as assessed by measuring TSH and the thyroid hormones appears to be maintained in the workers exposed to low levels of elemental mercury.”

3.3.8 Effects on the immune system

250. The ability of mercury to induce immune-mediated disease has been thoroughly investigated in mice and rats experimentally exposed to inorganic mercury compounds, in most studies divalent mercury, but also mercury vapour. The type of response depends on the strains, some of them being susceptible to autoimmune disease and some being resistant. It is therefore assumed that the genotype is probably important also for the potential immunological effects in humans. For a review, see Eneström and Hultman (1995) and Sweet and Zelikoff (2000). Some studies in humans occupationally exposed to moderate levels of elemental mercury reported changes in biochemistry of the immune response system (see Pirrone *et al*., 2001).

3.3.9 Effects on the skin (dermal)

251. Exposure to elemental mercury vapours for acute or intermediate duration may result in a response known as acrodynia or "pink disease", which is characterized by peeling palms of hands and soles of feet, excessive perspiration, itching, rash, joint pain and weakness, elevated blood pressure and tachycardia (Fagala and Wigg, 1992; Karpathios *et al*., 1991; Schwartz *et al*., 1992). Also, rash and stomatitis have been reported after high inhalation exposures (Bluhm *et al*., 1992; Barregard *et al*., 1996).

3.3.10 Reproductive and developmental effects

252. A study of the pregnancies of Polish dental professionals showed a high frequency of malformations of a nonspecified nature (Sikorski *et al.*, 1987). In contrast, a study of Swedish dental professionals found no increases in malformations, abortions, or stillbirths (Ericsson and Källén, 1989). An increase in low birth weight infants was noted in the offspring of female dental nurses (Ericsson and Källén, 1989); however, in this same study similar effects were not observed for either dentists or dental technicians, and socioeconomic factors may have contributed to the effects observed.

253. Studies of occupational exposure indicate that exposure to elemental mercury may affect human reproduction. Possible effects are increased spontaneous abortions, congenital anomalies, and reduced fertility among women.

254. In occupational exposure studies, paternal exposure to metallic mercury does not appear to cause infertility or malformations (Alcser *et al.*, 1989; Lauwerys *et al.*, 1985). However, a study of pregnancy outcomes among the wives of 152 mercury-exposed men revealed an increased incidence of spontaneous abortions (Cordier *et al.*, 1991). Preconception paternal urinary mercury concentrations above 50 µg/l were associated with a doubling of the spontaneous abortion risk. Elghancy *et al.* (1997) compared the pregnancy outcomes of 46 mercury-exposed workers to those of 19 women who worked in nonproduction areas of the same factory. Women exposed to inorganic mercury had a higher rate of births with congenital anomalies. Concentrations were up 0.6 mg/m^3.

255. However, no significant differences in stillbirths or miscarriage rates were noted between the two groups of women. Also, no increase in spontaneous abortions was observed among dental assistants (potentially exposed to mercury vapour) in a historical prospective study of pregnancy outcomes among women in 12 occupations (Heidam, 1984). Similarly, no relationship between the amalgam fillings prepared per week and rate of spontaneous abortions or congenital abnormalities was observed in a postal survey in California (Brodsky *et al.*, 1985). No excess in the rate of still births or congenital malformations was observed among 8,157 infants born to dentists, dental assistants, or technicians, nor were the rates of spontaneous abortions different from the expected values (Ericsson and Källén, 1989). Rowland *et al.* (1994), however, found that the probability of conception among female dental hygienists who prepared more than 30 amalgams per week and had at least five poor hygiene practices when handling mercury was only 63 percent of that among unexposed controls. Women with lower exposures, however, were more fertile than unexposed controls. A large study conducted in Norway compared reproductive success rates among 558 female dental surgeons with those of 450 high-school teachers (Dahl *et al.*, 1999). They concluded that exposure to mercury, benzene, and chloroform was not associated with decreased fertility except for a possible mercury effect on the last pregnancy of multiparous dental surgeons.

3.3.11 Genotoxicity

256. Two occupational studies (Anwar and Gabal, 1991; Popescu *et al.*, 1979) reported on workers inhaling inorganic mercury; the data were inconclusive regarding the clastogenic activity of inorganic mercury. Workers involved in the manufacture of mercury fulminate ($Hg[OCN]_2$) had a significant increase in the incidence of chromosomal aberrations and micronuclei in peripheral lymphocytes when compared to unexposed controls (Anwar and Gabal, 1991). There was no correlation between urinary mercury levels or duration of exposure to the increased frequency of effects; the study authors concluded that mercury may not have been the clastogen in the manufacturing process. In a study by Popescu *et al.* (1979), 18 workers exposed to a mixture of mercuric chloride, methylmercuric chloride and ethylmercuric chloride had significant increases in the frequency of acentric fragments. Barregard *et al.* (1991) demonstrated a correlation between cumulative mercury exposure and induction of micronuclei among a group of chlor-alkali workers, suggesting a possible genotoxic effect. Other studies did not observe genotoxic effects among workers exposed to mercury vapour (Vershaeve *et al.*, 1976, 1979; Mabille *et al.*, 1984).

3.4 Interactions – possible confounding effects of certain nutrients

257. The evidence is inconclusive and uncertain on the possible effects of various nutrients in relation to mercury toxicity. Nonetheless, limited evidence suggests that diet and nutrition may potentially reduce or enhance the toxicity of mercury, depending on dietary patterns and specific substances in the diet. Thus, nutritional status and dietary interactions might potentially affect the outcome of mercury studies, either by influencing the toxicity of mercury or by having effects on the endpoints measures. Some limited evidence suggests that protective effects of some nutrients (such as selenium, vitamin E, omega-3 fatty acids) might possibly reduce potentially harmful effects of mercury. Other components of the diet (such as ethanol) might possibly enhance toxicity of mercury. Also, mal-nourishment might possibly affect study results either by directly reducing the sensitivity of an endpoint tested or by exacerbating the effects of mercury and thereby increasing the sensitivity to mercury toxicity. Other nutritional factors such as iron or folate deficiencies that disrupt neuronal development might also possibly influence the impact of mercury.

258. Moreover, in studies of mercury toxicity to humans, other pollutants in the diet (such as PCBs) may prevent obtaining clear information on mercury toxicity. This is particularly the case when investigating more subtle toxic effects at low exposure levels, and much effort has been given to eliminating the misinterpretation of results due to such so-called "confounders." More information on possible interactions of nutrients and other components of food can be found, among others, in the following references: Block, 1985; Bulat *et al.*, 1998; Chalon *et al.*, 1998; Chapman and Chan, 2000; Drasch *et al.*, 1996; Falnoga *et al.*, 2000; Goyer, 1997; Kling *et al.*, 1987; McNeil *et al.*, 1988; NRC, 2000; Petridou *et al.*, 1998; Rowland *et al.*, 1986; Rumbeiha *et al.*, 1992; Turner *et al.*, 1981 and WHO/IPCS, 1990.

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 µg/day (WHO/IPCS, 1991; for more details, consult reference).

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

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

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

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

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

4.3.2 General aspects of dietary mercury intake

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

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

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

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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 (µg/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.

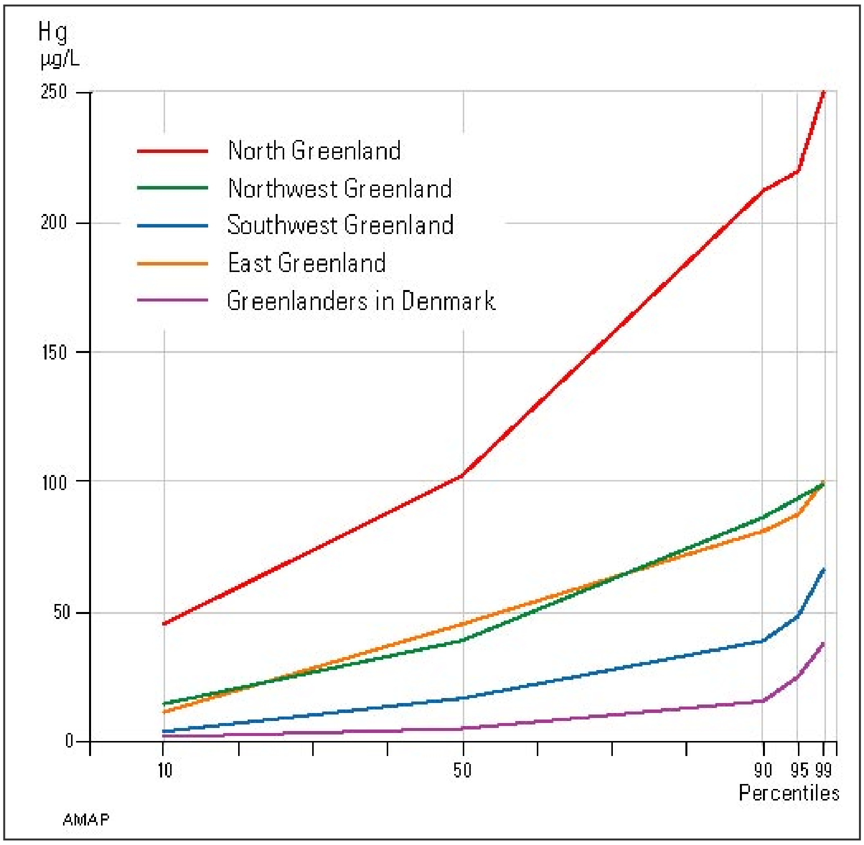


Figure 4.1 Distribution (in percentiles) of whole blood mercury concentrations in four regions in Greenland and in Greenlanders living in Denmark (AMAP, 1998, based on 1988 measurements). Original figure presented courtesy of AMAP, Norway.

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.

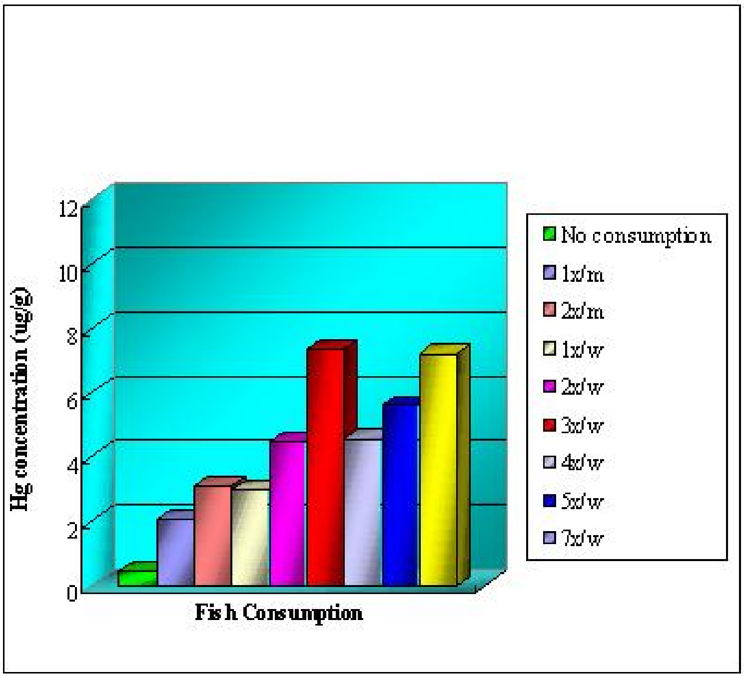
330. Some studies in the Amazonas have shown adverse effects from mercury exposure on humans. For example, in the Tapajós river community of Brazil, cognitive deficits have recently been reported in 7-year children who were exposed, in uterus, to mercury levels corresponding to maternal hair mercury 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)

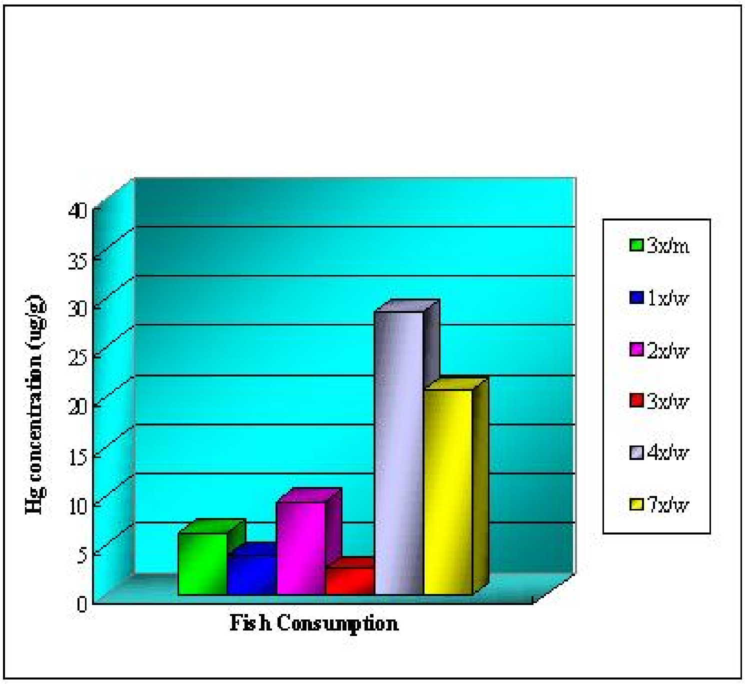


Figure 4.2 Total mercury concentrations in hair vs fish consumption in two regions of the State of Amapá, Brazil (from Vasconcellos et al.*, 1998, submitted by Brazil, sub68govatt1)*

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	Contami-nation 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, inside Minamta Bay Scorpionfish, outside Minamata Bay	**0.655** mg/kg ± 0.162 **0.511** mg/kg ± 0.241 **0.603** mg/kg ± 0.216 **0.531** mg/kg ± 0.194 **0.431** mg/kg ± 0.163	1978 1993 1983 1990 1999			Yasuda *et al*, in national submission from Japan, sub6gov
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 Perch	0.1 – **2.5** mg/kg 0.1 – **2.5** mg/kg	1988-1994			National submission from Norway, sub70gov
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: Barbel (*Barbus barbus*)	0.053-**7.329** mg/kg ww (mean 0.728 mg/kg, 29 samples)	1995-2000			Comments from Slovak Republic (Comm-14-gov)
	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.

5 Impacts of mercury on the environment

5.1 Overview

Build-up of mercury in food webs

337. A very important factor in the impacts of mercury to the environment is its ability to build up in the organisms and up along the food chain. Although all forms of mercury can accumulate to some degree, methylmercury is absorbed and accumulates to a greater extent than other forms. Inorganic mercury can also be absorbed, but is generally taken up at a slower rate and with lower efficiency than is methylmercury (US EPA, 1997). The biomagnification of methylmercury has a most significant influence on the impact on animals and humans. Fish appear to bind methylmercury strongly, nearly 100 percent of mercury that bioaccumulates in predator fish is methylmercury. Most of the methylmercury in fish tissue is covalently bound to protein sulfhydryl groups. This binding results in a long half-life for elimination (about two years; Wiener and Spry, 1996). As a consequence, there is a selective enrichment of methylmercury (relative to inorganic mercury) as one moves from one trophic level to the next higher trophic level.

Bioaccumulation and biomagnification

The term **bioaccumulation** refers to the net accumulation over time of metals within an organism from both biotic (other organisms) and abiotic (soil, air, and water) sources.
The term **biomagnification** refers to the progressive build up of some heavy metals (and some other persistent substances) by successive trophic levels – meaning that it relates to the concentration ratio in a tissue of a predator organism as compared to that in its prey (AMAP, 1998).

338. In contrast to other mercury compounds the elimination of methylmercury from fish is very slow (US EPA, 1997). Given steady environmental concentrations, mercury concentrations in individuals of a given fish species tend to increase with age as a result of the slow elimination of methylmercury and increased intake due to changes in trophic position that often occur as fish grow to larger sizes (i.e., the increased fish-eating and the consumption of larger prey items). Therefore, older fish typically have higher mercury concentrations in the tissues than younger fish of the same species.

339. The mercury concentrations are lowest in the smaller, non-predatory fish and can increase many-fold on the way up the food chain (AMAP, 1998). Apart from the concentration in food, other factors affect the bioaccumulation of mercury. Of most importance are the rates of methylation and demethylation (see section 2.3) by mercury methylating bacteria (e.g., sulphate reducers). When all of these factors are combined, the net methylation rate can strongly influence the amount of methylmercury that is produced and available for accumulation and retention by aquatic organisms. As described in section 2.3, several parameters in the aquatic environment influence the methylation of mercury and thereby its biomagnification. While much is generally known about mercury bioaccumulation and biomagnification, the process is extremely complex and involves complicated biogeochemical cycling and ecological interactions. As a result, although accumulation/magnification can be observed, the extent of mercury biomagnification in fish is not easily predicted across different sites.

340. At the top levels of the aquatic food web are fish-eating species, such as humans, seabirds, seals and otters. The larger wildlife species (such as eagles, seals) prey on fish that are also predators, such as trout and salmon, whereas smaller fish-eating wildlife (such as kingfishers) tend to feed on the smaller

forage fish. In a study of fur-bearing animals in Wisconsin, the species with the highest tissue levels of mercury were otter and mink, which are top mammalian predators in the aquatic food chain. Top avian predators of aquatic food chains include raptors such as the osprey and bald eagle (US EPA, 1997). Thus, mercury is transferred and accumulated through several food web levels (US EPA, 1997). Aquatic food webs tend to have more levels than terrestrial webs, where wildlife predators rarely feed on each other, and therefore the aquatic biomagnification typically reaches higher values.

Mercury compounds toxic to wildlife

341. Methylmercury is a central nervous system toxin, and the kidneys are the organs most vulnerable to damage from inorganic mercury. Severe neurological effects were already seen in animals in the notorious case from Minamata, Japan, prior to the recognition of the human poisonings, where birds experienced severe difficulty in flying, and exhibited other grossly abnormal behaviour. Significant effects on reproduction are also attributed to mercury, and methylmercury poses a particular risk to the developing fetus since it readily crosses the placental barrier and can damage the developing nervous system.

342. In birds, adverse effects of mercury on reproduction can occur at egg concentrations as low as 0.05 to 2.0 mg/kg (wet weight). Eggs of certain Canadian species are already in this range, and concentrations in the eggs of several other Canadian species continue to increase and are approaching these levels.

343. The levels of mercury in Arctic ringed seals and beluga whales have increased by 2 to 4 times over the last 25 years in some areas of the Canadian Arctic and Greenland (Muir *et al*., 2001; Wagemann *et al*., 1996). In warmer waters as well, predatory marine mammals may also be at risk. In a study of Hong Kong’s population of hump-backed dolphins, mercury was identified as a particular health hazard, even more than other heavy metals.

Vulnerable ecosystems

344. Recent evidence suggests that mercury is responsible for a reduction of micro-biological activity vital to the terrestrial food chain in soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics. Preliminary critical limits to prevent ecological effects due to mercury in organic soils have been set at 0.07-0.3 mg/kg for the total mercury content in soil. (Pirrone *et al.*, 2001)

345. On the global scale, the Arctic region has been in focus recently because of the long-range transport of mercury. However, impacts from mercury are by no means restricted to the Arctic region of the world. The same food web characteristics - and a similar dependence on a mercury contaminated food source - are found in specific ecosystems and human communities in many countries of the world, particularly in places where a fish diet is predominant.

346. Rising water levels associated with global climate change may also have implications for the methylation of mercury and its accumulation in fish. For example, there are indications of increased formation of methylmercury in small, warm lakes and in many newly flooded areas.

347. This chapter is not intended to provide a comprehensive synthesis of the literature on mercury exposure, effects and risks to ecological receptors. Rather it represents a summary of selected reviews of the topic, as well as data and comments submitted during the drafting process.

348. Different parts of the descriptive text in this chapter were based on Pirrone *et al.* (2001), US EPA (1997), the Canadian government submission of information to UNEP (sub42gov) and the submission from the Nordic Council of Ministers (sub84gov).

5.2 Eco-toxicological effect levels

349. Over the years numerous scientific papers, reports and reviews have been published on mercury and methylmercury toxicity and ecotoxicity. The reader is referred to the comprehensive coverage in the WHO IPCS Monographs on Mercury (WHO/IPCS, 1991), Methylmercury (WHO/IPCS, 1990) and Mercury - Environmental Aspects (WHO/IPCS, 1989) for detailed information. In this text a broader perspective is adopted in combination with some of the data from the recent decade as compiled in reviews (US EPA, 1997; Pirrone *et al*., 2001; the Canadian submission to UNEP (sub42govatt1); and others).

350. This section will primarily focus on the mercury concentrations and doses resulting in effects in individual organisms. The data are mostly laboratory results or from epidemiological studies. Despite a number of field investigations of the potential effects of mercury on free-living aquatic and terrestrial wildlife, the effects of mercury at higher levels of biological organization (e.g., ecosystem, community, population) are not well understood, as indicated in the review by US EPA (1997).

351. Mercury exposure may result in severe neurological effects, and this was seen in Minamata, Japan, from about 1950-1952 (prior to the recognition of human poisonings), where birds experienced severe difficulties in flying, and exhibited other grossly abnormal behaviour (US EPA, 1997). Signs of neurological disease including convulsions, fits, highly erratic movements (mad running, sudden jumping, bumping into objects) were observed among domestic animals, especially cats whose diets were high in seafood.

5.2.1 Mammals

352. The bulk of data on mammals have been generated through laboratory experiments on mice, rats and other typical laboratory animals, for the evaluation of risk for humans. These findings are not evaluated in this text, where wildlife species are the main focus.

353. Laboratory studies under controlled conditions have been used to assess the effects of methylmercury (from a fish diet) on mink and otter (and several avian species). According to the US EPA (1997), effects can occur at a dose of 0.18 mg/kg body weight per day or 1.1 mg/kg methylmercury in diet (LOAEL established by US EPA for mink from Wobeser *et al.*, 1976). Death may occur in species at 0.1-0.5 mg/kg body weight per day or 1.0-5.0 mg/kg in the diet. Smaller animals (for example, minks, monkeys) are generally more susceptible to mercury poisoning than are larger animals (for example, mule deer or harp seals).

354. The US EPA has developed methylmercury wildlife criteria for two mammal species in the USA (mink and otter) relying on an aquatic diet (US EPA, 1997). The wildlife criteria are based on a methylmercury level in water (from which the animals get their food) that is thought not to harm the species. The criteria were calculated from effect concentrations (LOEL and NOEL) and bioaccumulation factors.

355. The derived Mammalian Wildlife Criteria for methylmercury were 57 picograms per litre (pg/l) for mink and 42 pg/l for river otter. The US EPA noted that the criteria reflect effect levels that are just over two orders of magnitude higher than those forming the basis for their human reference dose, and that the wildlife criteria do not cover more subtle effects like those observed in humans recently (US EPA, 1997).

356. It should be mentioned that methylmercury is rarely measured in water, and that concentrations in the Wildlife Criteria are extraordinarily difficult to measure. Recent total mercury concentrations in unpolluted (only diffuse load) surface water are reported in the range of 0.1 to 5 ng/l. A number of studies have shown that methylmercury typically amounts to 1-10 percent of total mercury in water. Assuming a mercury concentration of 1 ng/l in the water, methylmercury will range from 10-100 pg/l and it will thus not be uncommon to exceed the Wildlife Criteria.

357. Lethal or harmful effects in marine and terrestrial mammals are reported in AMAP (1998) when mercury concentrations exceed 25 to 60 mg/kg wet weight in kidneys and liver. Methylmercury is a central nervous system toxin and the kidneys are the organs most vulnerable to damage from inorganic mercury. Significant effects on reproduction are attributed to mercury, but in particular methylmercury poses a risk to the developing fetus since it readily crosses the placental barrier (AMAP, 1998).

5.2.2 Birds

358. Eggshell thinning in birds was observed in the 1950's and 1960's as some of the first environmental consequences of the spreading of mercury (and other environmental toxins); in this case methylmercury was used as seed dressing, and severe poisoning of wildlife was observed in Scandinavia and North America. The populations of pheasants and other seed-eating birds, as well as birds of prey (e.g. hawks and eagles), were drastically reduced and in some areas nearly disappeared (Ramel, 1974). Therefore birds, feathers and eggs have been used since then for monitoring the effects of mercury, and a number of effect values are available.

359. Acutely poisoned birds usually have whole body residues of mercury in excess of 20 mg/kg wet weight (US EPA, 1997).

360. Burger and Gochfeld (1997) quote a number of studies relating concentrations of mercury in eggs to a variety of effects in birds, particularly reduced hatchability, chick survival and other reproductive failures. The effect concentrations range from 0.05-5.5 mg/kg wet weight in eggs with the majority around 0.5-1.0 mg/kg wet weight, see table 5.1. It should be noted that effect levels vary among species, depending on their feeding preferences, for example, and that extrapolation to other species should be done with caution.

Table 5.1 Summary of acute and other adverse mercury effect levels in birds.

Level	**Concentration**	**Reference**
Acute effects level		
Whole body residue	20 mg/kg wet weight	US EPA, 1997
Other adverse effect levels		
Eggs	0.5-2.0 mg/kg wet weight	Canadian submission, sub42gov
Eggs	0.05-5.5 mg/kg wet weight	Burger and Gochfeld, 1997
Feathers (laboratory data)	5-65 mg/kg dry weight	Burger and Gochfeld, 1997
Fish diet	0.3-0.4 mg/kg wet weight (in fish)	Scheuhammer *et al.*, 1998 in Pirrone *et al.*, 2001.
Fish diet (field studies)	0.2 - 0.4 mg/kg wet weight	Various sources quoted in Canadian submission, sub42gov (see text below).
Fish diet (laboratory data)	> 0.5 mg/kg wet weight	Sources quoted in Canadian submission, sub42gov (see text below).

361. In particular, the ability of birds to demethylate methylmercury (which may be related to their dietary preference – fish diet versus vegetable diet) has important implications for avian risk assessment since most tests have been conducted on non-fish-eating species. In addition, the confounding effects of co-exposure to selenium on methylmercury toxicity should be mentioned, as selenium has been shown in laboratory studies to elicit protective and in some cases antagonistic effects on mallards depending on the life stage (US EPA, 1997).

362. Sensitivity to mercury toxicity is species specific, making it difficult to predict toxic thresholds for mercury in eggs of seabirds. Nevertheless, laboratory studies on other bird species indicate that adverse effects of mercury on reproduction can occur at egg concentrations as low as 0.5 to 2.0 mg/kg wet wt. (Burgess and Braune, 2001). The eggs of Leach's Storm-Petrel are already in this range of mercury concentrations, and concentrations in the eggs of several other Canadian species continue to increase and are approaching these levels.

363. Concentrations of mercury in feathers associated with adverse effects are reported in the range 5-65 mg/kg dry weight (Burger and Gochfeld, 1997), see table 5.1.

364. In controlled feeding studies concentrations of mercury down to 0.5 mg/kg wet weight in the diet have been shown to produce reproductive and behavioural effects. Field studies on free-living common loons indicate negative impacts when mercury in prey fish reaches 0.2 - 0.4 mg/kg wet weight (Barr, 1986; Nocera and Taylor, 1998; Scheuhammer, 1995).

365. It has been suggested (though not proven) that methylmercury may cause immuno-toxicological effects and increased prevalence of chronic diseases in great white herons (Spalding *et al.*, 1994). This is consistent with immunotoxic findings of methylmercury in laboratory mammals, and may be a particularly important consequence of methylmercury exposure to wildlife populations, which frequently encounter infectious diseases (USA, comm-24-gov). For reviews on immunotoxicological and histopathological effects of methylmercury on wild birds, see Wolfe *et al.* (1998) and Spalding *et al.* (2000).

366. Wildlife criteria for birds were established by the US EPA for kingfisher, loon, osprey and bald eagle, and range from 33 to 100 pg methylmercury/l water, see table 5.2. The US EPA noted that the criteria reflect effect levels that are just over two orders of magnitude higher than those forming the basis for the human reference dose, and that the wildlife criteria do not cover more subtle effects like those recently observed for humans (US EPA, 1997).

Table 5.2 Wildlife Criteria for methylmercury in water (US EPA, 1997).

Organism	Wildlife Criterion (pg/l) *
Kingfisher	33
Loon	82
Osprey	82
Bald eagle	100

Note: * 1 pg (picogram) is 10^{-12} g.

5.2.3 Fish

367. While toxic levels in adult fish are believed to occur at levels well above those typically encountered in the environment (except in grossly polluted systems), recent evidence suggests that mercury exposure to early life stages in some fish can affect growth, development and hormonal status at levels within a factor of 10 of levels encountered in "pristine" lakes (i.e., lakes where there are no known mercury point sources; US EPA, 1997*(Volume VI)*; Friedman *et al.*, 1996; Wiener and Spry, 1996). Furthermore, Wiener and Spry (1996) concluded that while direct waterborne exposure to methylmercury is generally not a serious concern to adult fish, effects from indirect exposure via dietary uptake and maternal transfer of methylmercury to eggs and developing embryos occur at 1 percent of levels affecting adult fish, and may be a concern (i.e., embryo mortality in lake trout eggs at 0.07 - 0.10 µg/g w.w. versus toxicity in adults at 10-30 µg/g). Although not conclusive, they further suggest that the reproductive success of some walleye populations may be impaired by existing levels of mercury exposure (USA, comm-24-gov).

368. Mercury concentrations and biomagnification in fish have been assessed extensively due to the risks of mercury to humans through fish in the diet. In general, acute toxicity (96 hour LC_{50}) ranges from 33-400 µg/l for freshwater fish, with seawater fish being less sensitive (WHO/IPCS, 1989).

5.2.4 Micro-organisms

369. Mercury is toxic to micro-organisms and has long been used to inhibit the growth of bacteria in laboratory experiments (WHO/IPCS, 1990). Effects of inorganic mercury have been reported at concentrations of 5 µg/l in cultures of micro-organisms, and of organic mercury compounds at concentrations

at least 10 times lower (WHO/IPCS, 1991). As mentioned, organic mercury compounds have been used as fungicidal seed dressings.

370. Investigations in temperate forest soils have shown that adverse effects on microbial processes can be expected at concentrations corresponding to the present level increased by a factor of about 3. (Rundgren *et al.*, 1992 ; Tyler, 1992, in Pirrone *et al.*, 2001). Recent research indicates, however, that impacts may already be evident in soils over large parts of Europe (Johansson *et al.*, 2001; Johansson, 2001) – and potentially in many other places in the world with similar soil characteristics.

371. Recently, preliminary critical limits to prevent ecological effects from mercury in organic soils have been set to 0.07–0.3 mg/kg for the total mercury content in soil. The limits were developed by an international expert group on effect-based critical limits for heavy metals, working within the framework of the UN ECE Convention on Long-Range Transboundary Air Pollution (Curlic *et al.*, 2000; quote from Pirrone *et al.*, 2001). The bioavailability of mercury in soil has a strong influence on its toxicity. This means that mainly the water-dissolved fraction of the mercury present is the determining factor for its toxicity in soil environments.

5.2.5 Other species

372. Aquatic plants are affected by mercury in the water at concentrations approaching 1 mg/l for inorganic mercury, but at much lower concentrations of organic mercury (WHO/IPCS, 1991). High concentrations of inorganic mercury affect macroalgae by reducing the germination (AMAP, 1998).

373. Aquatic invertebrates vary greatly in their susceptibility to mercury. Generally, larval stages are more sensitive than adults. In 48-hour exposures, 50 percent mortality in larvae often occur at concentrations around 10 µg/l, which typically is 100 times lower than in adults. Oyster larvae are even more sensitive to mercury (WHO/IPCS, 1989). Toxicity is also affected by temperature, salinity, dissolved oxygen, and water hardness (Boening, 2000).

374. For other classes of animals (e.g. reptiles, amphibians), little data exist from which to draw conclusions regarding risk levels. Several species (e.g. alligator, snapping turtle) are expected to experience significant methylmercury exposure due to their piscivorous feeding habits. Some data on residues in alligators are available, but corresponding effect levels are lacking (USA, comm-24-gov).

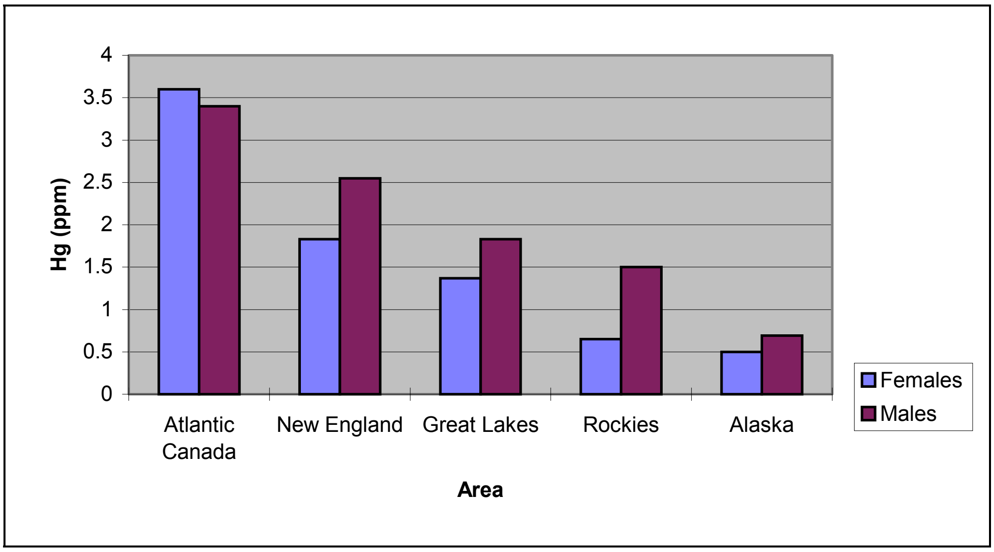
375. There is very limited information on toxicity in the terrestrial environment, apart from the mammals, birds and the recent micro-organism data. Terrestrial plants are fairly insensitive to the toxic effects of mercury compounds. Mercury is, however, accumulated in higher plants, especially in perennials (Boening, 2000). The primary effect observed in plants is associated with root tips (Boening, 2000).

5.3 Ecosystems at risk and vulnerable species

376. This section describes the increased risks to ecosystems and to various species due to the specific properties of mercury and the environment. On the global scale, the Arctic region has been in focus recently because of mercury's particular tendency to long-range transport. It is important to acknowledge, however, that impacts of mercury are by no means restricted to the Arctic region. The same food web characteristics and similar dependence on a mercury contaminated food source are found in specific ecosystems and human communities in many countries around the world, particularly where a fish diet is predominant. Consequently, fish-eating birds and mammals are more highly exposed to mercury than any other known denizens of the aquatic ecosystem (Pirrone *et al.*, 2001).

377. In the absence of a specific local mercury source, the pattern of mercury deposition over a country or continent strongly influences which eco-regions and eco-systems are more highly exposed.

378. For example, in Canada and the Northern USA the mercury levels in loons decreases from east to west (Canadian submission, sub42gov), see figure 5.1.



Source: Burgess, 1998; Evers *et al.*, 1998 in the Canadian submission sub42gov.
(ppm = mg/kg)

Figure 5.1 Mean mercury levels in loon blood in Canada and the Northern USA from East to West (Canadian submission, sub42gov)

5.3.1 Aquatic food webs

Marine environment

379. The top marine predators are especially vulnerable to mercury exposure for reasons previously discussed. The levels of mercury in Arctic ringed seals and beluga whales have increased 2- to 4-fold over the last 25 years in some areas of the Canadian Arctic and Greenland (Muir *et al*., 2001; Wagemann *et al*., 1996). However, it is not yet fully understood how much of the mercury found in the biological environment is derived from natural sources versus human activity.

380. In warmer waters as well, predatory marine mammals may be exposed to mercury levels that are health threatening. In a study of Hong Kong's population of hump-backed dolphins, mercury was identified as a particular health hazard, even more than other heavy metals (Parsons, 1998).

381. Recent knowledge points to the sub-surface parts of the oceans, which are low in oxygen, as a source of conversion of mercury to methylmercury, fueling the latter's bioconcentration in fish and food web. Concentrations of methylmercury in fish species increased 4-fold from a depth of less than 200 m to more than 300 m, with no further increases, however, even down to about 1200 m (Monteiro *et al.,* 1999).

Freshwater environments

382. In their recent report, the US EPA (1997) presented a number of characteristics of the freshwater ecosystems that are most at risk from airborne releases of mercury:

- They are located in areas where atmospheric deposition of mercury is high;
- They include surface waters already affected by acid deposition;
- They possess characteristics other than low pH that result in high levels of bioaccumulation; and/or
- They include sensitive species.

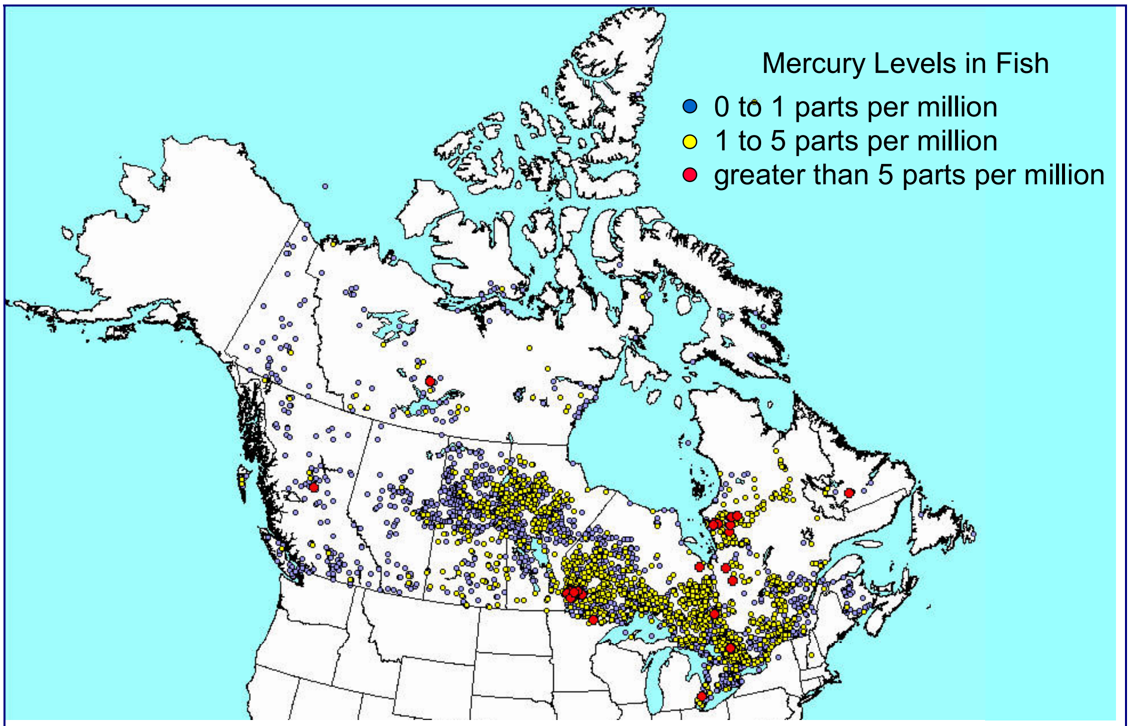
383. It could be added, for other parts of the world, that freshwater bodies subject to local direct releases of mercury are also at risk.

384. The Canadian environmental authorities likewise recognise that "fish-eating species in regions with higher mercury deposition, and in areas that favour methylation such as partially acidified water-

sheds, watersheds with large wetlands high in dissolved organic carbon, and reservoirs, are expected to be most at risk from increased dietary mercury exposure" (Canadian submission, sub42govatt1).

385. Surveys have shown that approximately 30 percent of Ontario lakes sampled contained small fish (<250 g) with mercury concentrations averaging more than 0.3 ppm, the level suggested as the dietary threshold for severe reproductive impairment in fish-eating birds (loons) (Scheuhammer and Blancher, 1994, in Canada submission, sub42gov).

386. The map in figure 5.2 (subject to updates, with additional data for Atlantic Canada forthcoming) indicates, by range, the mercury concentrations in freshwater fish from 3,200 different locations in Canada.



The Canadian National Database for Mercury Levels in Freshwater Fish has information for over 3200 locations. Many areas have naturally high levels of mercury due to local geology or other factors. Areas without coloured dots have not been sampled for mercury.

Source: Draft Status and Trends Report, Environment Canada, 2001.

Figure 5.2 Mercury levels in freshwater fish in Canada (Canadian submission, sub42gov).

Climate changes

387. Other factors remaining constant, mercury contamination of fish tends to be higher in small lakes than in large lakes. This may be explained by small lakes being warmer, increasing the methylation of mercury. This relationship may have further important implications for the methylation of mercury and its accumulation in fish in the context of long-term climate change (Canadian Dept. of Fisheries and Oceans, 1998).

388. Also, rising water levels and newly flooded areas, which might occur as a result of climate change, could possibly influence the rate at which mercury is released and methylated, as such events have been shown to be a source of increased mercury release and methylmercury formation (Canadian submission, sub32gov, and Canadian comments, comm-20-gov).

5.3.2 The terrestrial food web

389. Historically, the use of organic mercury compounds for agricultural seed dressing has resulted in mercury exposures of seed-eaters, particularly birds and rodents (Fimreite, 1970; Johnels *et al*., 1979, in Pirrone *et al*., 2001). Where the use of mercury-coated seeds continues, some impact on the terrestrial environment is expected.

390. Until recently, inorganic mercury was not considered a major source of effects in the soil compartment because it is bound to the soil particles and is not very bioavailable to plants or organisms. In fact, the uptake of gaseous elemental mercury through leaves is much more efficient than the uptake of soil mercury (Hg(II)) in roots, and the main exposure of plants may therefore be through the air.

391. New studies from both the field and laboratory have shown that a mercury-related reduction of microbiological activity in soils is likely taking place in southern Sweden (Bringmark and Bringmark 2001a; 2001b; Palmborg *et al*., 2001; all in Pirrone *et al*., 2001). The findings in Sweden and in other countries show that the microbiological activity in the topsoil appears to be very sensitive to the mercury burden, and that significant impacts may already be taking place in forest soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics (Johansson *et al*., 2001; Johansson, 2001; all in the submission from the Nordic Council of Ministers (sub84gov).

392. The microbiological activity in soil is vital to the processing of carbon and nutrients in the soil, and the health of the microbiological community has a great effect on the living conditions of trees and soil organisms, which form the basis for the terrestrial food chain.

5.3.3 Arctic region

393. The Arctic region is affected by long-range transported mercury. In the Arctic sediments mercury shows increasing concentrations, and there is some evidence that the concentration in some marine mammals has increased by a factor of 2- to 4-fold over the last 25 years in some areas of the Canadian Arctic and Greenland (Muir *et al*., 2001; Wagemann *et al*., 1996; both in Canadian submission, sub42gov). To what extent that is due to increased mercury levels, or to increases in the fraction of the total mercury that is bio-available - a possible outcome of the current warming trend and increased biotic activity in the Arctic - is a subject of current discussion in AMAP (Canadian comments, comm-20-gov). The Arctic marine food web is often in the spotlight regarding the risk to ecosystems and the impact on human populations from mercury. In the Arctic, the aquatic food web is very long, with three levels of predators (including humans) at the top, and therefore high concentrations of biomagnified mercury occur there.

394. A wealth of information is available on concentrations and trends for mercury, particularly from AMAP, which published a comprehensive assessment report in 1998, with another assessment report due in 2002/2003. However, it remains uncertain whether mercury poses a health threat to the most highly exposed groups of Arctic marine mammals.

395. Accumulation and exposure of top predators also occurs in subarctic and temperate regions where the biomagnification is seen most clearly in aquatic environments (US EPA, 1997). The animals considered at most risk of adverse effects from mercury are again the species depending on a diet of fish (e.g. otters, seals, eagles) or a diet of the fish-eating species (e.g. bears).

396. For comparison, figure 5.3 shows mercury concentration levels found in different tissue types from Arctic fish, birds and mammals. Note that concentrations are presented on a logarithmic scale, meaning that large differences in concentrations between trophic levels visually appear small. The figure was developed in AMAP (1998).

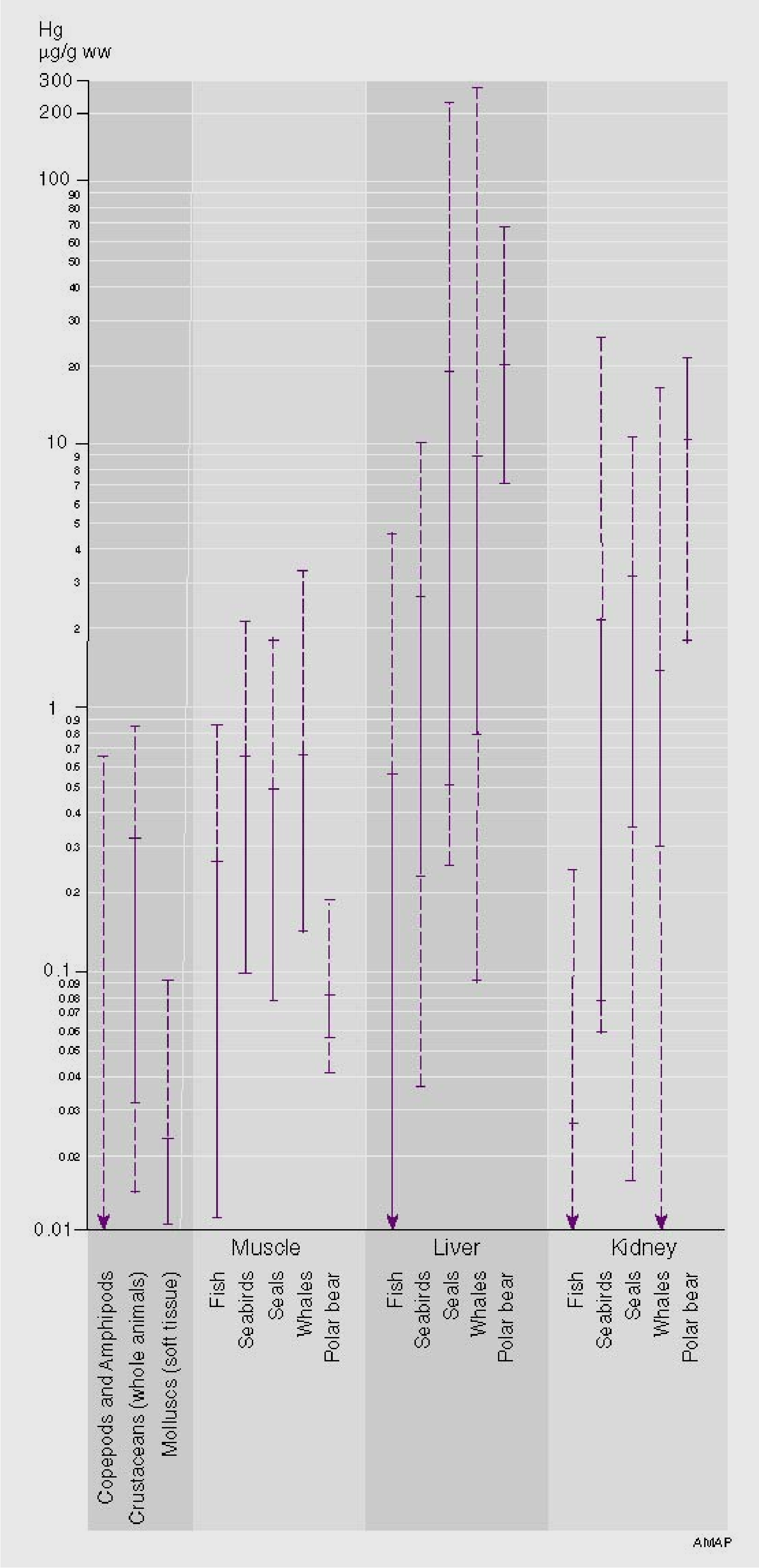


Figure 5.3 *Summary of ranges of mercury concentrations found in Arctic marine organisms (means). Solid parts of the lines indicate ranges for Greenland data from Dietz et al. (2000), where the analytical data have been critically evaluated. The figure with concentration levels was originally produced in AMAP (1998), and is shown here courtesy of AMAP.*

5.3.4 Tropical issues

397. Large quantities of mercury are released to the waters of the Amazon and to the air of vast gold mining areas where mercury is used for amalgamation of the precious metal. This leads to impacts far beyond the local area, as seen in the Pantanal floodplain wetland in western Brazil, and parts of Bolivia and Paraguay (Leady and Gottgens, 2001). Post gold-rush mercury deposition was more than 1.5 times higher than the deposition rate at the Acurizal reference site, confirming a regional mercury effect due to gold mining. Post gold-rush (1980) mercury accumulation in Acurizal was also 2.1 times the rate reported for a global reference during that time period, suggesting an additional basin-wide effect over such reference sites. The authors estimated that only 2-8 percent of the total mercury released from gold mining was secured in sediments. The remainder of the mercury was lost to the atmosphere, downstream areas or stored in biota.

398. Other sources of intermediate increases in mercury mobilisation in tropical rain forests include slash-and-burn clearing of land for agriculture use or for mining operations. These activities permit mercury already present in the soil to be more exposed to mobilising mechanisms.

399. Biologically, there is a general difference between tropical and temperate ecosystems that may make tropical systems more vulnerable. In tropical ecosystems, more species are sustained and the niche of each species becomes smaller. In both ecosystems the top predators are the vulnerable species, but there are relatively fewer of each species in the tropics and this will magnify the effect of loss of individuals (Burger, 1997).

5.3.5 Reservoirs and wetlands

400. Reservoirs and wetlands are often mentioned as sources of methylmercury due to the methylation of inorganic mercury in the sediment (Canadian submission, sub42govatt1).

401. According to the Canadian submission (sub42gov), the “creation of reservoirs is an important source of mercury contamination of fish in Canada”, because the mercury present in newly flooded land becomes more available, and then more toxic due to the increased rate of conversion to methylmercury. Most fish caught in new reservoirs have mercury concentrations that exceed the consumption limit of 0.2 mg/kg wet weight recommended by Health Canada for people who frequently consume fish (Canadian submission, sub42gov).

402. In an investigation of mercury in feathers of birds from a number of tropical locations, Burger (1997) reported that although fish-eating birds generally had the highest mercury content, a similar content was found in Cattle Egrets from the Aswan dam area, although this species is an insect-eating bird. The author suggested that this may have been caused by more methylmercury in the food web due to a recent flood in the area initiating the methylation process.

403. An experiment in a wetland and pond at the Experimental Lakes Area in Northwestern Ontario demonstrated that natural wetlands are important sites of mercury methylation, and that flooding of wetlands increases methylation rates by a factor of more than 30 (Canadian submission, sub42gov). Increased concentrations of methylmercury were found in water, the food chain and eventually fish. Monitoring of boreal reservoirs indicates that concentrations of methylmercury in fish may return to normal 10 to 50 years after flooding.

5.3.6 Birds of prey and fish-eating birds

404. It is through fish consumption that mercury exposure in fish-eating birds occurs. Fish-eating birds in regions with high mercury in fish may be at risk of reproductive and behavioural affects (Scheuhammer, 1995, in Pirrone *et al.*, 2001).

405. The use of seabirds as biomonitors of marine environmental quality is widely recognised. Environment Canada (2001) stated that because of their widespread foraging habits and long lifespan, sea-

birds integrate mercury exposure over large geographic areas, and may be an excellent bioindicator of trends in long-range atmospheric transport of mercury. With birds the use of non-invasive monitoring strategies, such as collection of feathers and eggs, can be used.

406. The levels of mercury in Canadian Arctic seabird eggs have increased 2- to 3-fold over the last 20 years (Braune *et al*., 1999), similar to the increases reported in Arctic ringed seals and beluga whales over the same period. In a detailed survey of Canadian conditions, Burgess and Braune (2001) stated already at the time of the investigation that the mercury content in eggs indicated a reproductive risk:

> "Egg mercury levels were highest in Leach's Storm-Petrel and showed the greatest increase over time. Levels and increases over time were similar for Atlantic Puffins, Thick-billed Murres/Brünnich's Guillemots and Northern Fulmars. All these species occupy Arctic or North Atlantic waters year-round and forage offshore. In contrast, mercury levels in Double-crested Cormorant and Black-legged Kittiwake eggs did not increase over time. These species overwinter further south in the Atlantic Ocean. The levels indicate a potential threat to reproduction in some seabird species that will increase if trends continue".

407. Also, the concentrations in feathers have pointed to increasing levels of mercury, geographical distributions, and differences in food preference.

408. Monteiro and Furness (1997) have recently shown that feathers from fish-eating birds, which catch fish from the deeper mesopelagic layer, accumulate higher concentrations of mercury than birds feeding on fish from the upper parts of the water column. Based on comparison with feathers from pre-1931 museum samples, they have shown that the accumulation has also increased by 65-397 percent.

409. In a companion study, Monteiro *et al.* (1999) reported a similar relationship between bird populations in the Portuguese Atlantic islands and mainland colonies. The egg mercury concentrations were typically 1-5 mg/kg dry weight, depending on geographical location and species. These birds from rather isolated locations had egg mercury concentrations well above the lowest adverse effect level of 0.5 mg/kg dry weight proposed by Burger and Gochfeld (1997). Mercury levels in feathers were also higher than the adverse effect level of 5 mg/kg dry weight. Comparing to the adverse effect levels, Burger and Gochfeld (1997) mentioned that the birds of prey and fish-eaters most vulnerable include: hawks and eagles, gulls and skuas, herons and egrets, penguins, albatrosses, ducks, shorebirds, terns, puffins and alcids.

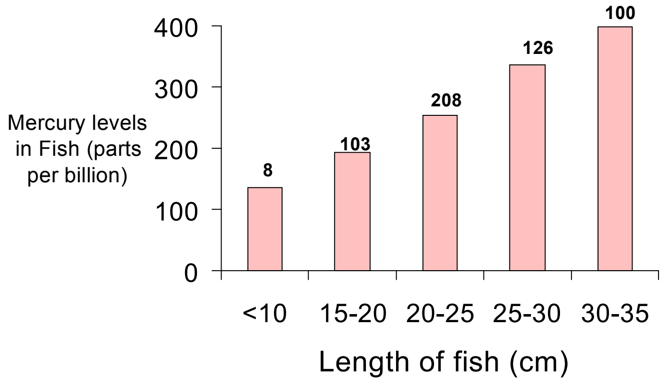
5.3.7 Canadian experience

410. The information in two recent reviews of the Canadian environment (Muir *et al.,* 1999; Braune *et al.,* 1999) provided a very detailed picture of the status and trends for mercury and other contaminants. The following section is built on these references.

411. Polar bears, ringed seals and beluga whales from western Arctic Canada had elevated mercury levels, apparently due to differences in sedimentary geology compared to the eastern Arctic. Belugas in contaminated environments (St. Lawrence estuary) had higher kidney and liver mercury content than belugas from five Arctic locations. Due to the lack of dose/response data for Arctic animals, the data cannot be directly interpreted with respect to impact, but rates of accumulation of mercury are higher (1.5-2.5 times) in recent samples of ringed seals and belugas than they were 10-20 years previously. This is in contrast to cadmium, which in the same period remains unchanged.

412. Levels of mercury in muscle of most species of Canadian Arctic freshwater fish cross the US EPA (1997) threshold (between 0.077 and 0.30 ppm for trophic level three fish) for protection of fish-eating birds and mammals. A number of lakes in the Northwest Territories and Northern Quebec have fish populations with levels exceeding the human consumption guidelines. The higher mercury levels are typically associated with larger, older fish.

413. Figure 5.4 shows average mercury levels in fish from Lake St. Clair, Ontario in southern Canada. Again, higher mercury levels are associated with larger, older fish.



Average levels of mercury in fish from Lake St. Clair, Ontario during the years 1990 to 1998.
The number above the bar is the number of fish used to calculate the average.

Source:Environment Canada, 2001

Figure 5.4 An example of observed fish mercury concentrations as compared to fish size.

414. Methylmercury is hardly released from fish at all, and methylmercury accounts for approximately 90 percent of the mercury in fish. In comparison with the terrestrial environment, virtually all mercury in the kidneys of caribou is of the less toxic inorganic form.

5.3.8 Ecological risk assessments

415. Numerous ecological risk assessments have been conducted in various places around the world. Table 5.3 contains examples of risk assessment and criteria development efforts.

Table 5.3 Examples of risk assessment and criteria development efforts, as aggregated by USA (comm-24-gov).

Study	**Finding**	**Reference**
1997 US EPA Mercury Study Report to Congress	0.077-0.3 ppm methylmercury is the estimated threshold in forage fish for protection of piscivorous wildlife. Suggests that it is probable that individuals of some highly exposed wildlife subpopulations are experiencing adverse toxic effects due to airborne mercury emissions	US EPA, 1997
1999 East Fork Popular Creek Risk Assessment	Moderate risks to mink (24% probability of at least a 15% mortality) Moderate risks to kingfisher (50% probability of at least a 12-28% decline in fecundity)	Moore *et al.,* 1999
2000 Everglades Risk Assessment	25% - 59% probability of exceeding methylmercury NOAEL for Wood Stork, Great Egret, Great Blue Heron	Rumbold *et al.,* 2000
Environment Canada Tissue Guidelines	< 0.033 ppm methylmercury in fish tissue recommended for wildlife protection	Caux *et al.,* 2000

416. Epidemiological studies that attempt to associate mercury exposure with effects measured in natural field settings offer another important line of evidence. While these studies are usually insufficient to conclusively establish causal relationships between stressor and response, they nonetheless add significantly to the evaluation of methylmercury impacts on wildlife populations. Field data contain important strengths such as reduced uncertainty associated with extrapolating effects between the laboratory and the field. This uncertainty is particularly important for methylmercury because several ecological risk assessments tend to be sensitive to relatively small amounts of uncertainty (i.e., a factor of 2 or 3 has important implications for the findings). Selected reviews of field epidemiological studies are found in US EPA (1997) for loons, bald eagles and other species in addition to Wolfe *et al.* (1998).

Local variations in ecosystem sensitivity

417. It is important to note the complex biogeochemistry of mercury with respect to a given food chain and in specific environments. The sensitivity of local ecosystems varies depending on natural conditions and anthropogenic influence. This also implies that the “critical loading” – the input of mercury that leads to enhanced mercury contamination and serious concerns for human health and the environment – varies according to local conditions. In some environments, fairly heavy mercury loads have only a limited effect on living matter, as either mercury is not efficiently bioaccumulated throughout the particular configuration of the local food chain, or the mercury is not easily methylated (Canadian comments, comm-20-gov). In other cases, ecosystems may be particularly sensitive to mercury loading. A good example is the Arctic region, where food chain characteristics seem to mediate biomagnification to very high levels, resulting in a high exposure of humans and other species at the highest trophic levels (see section 4.4.3). Another example may be the high sensitivity of the micro-flora in terrestrial environments of organic forest soils reported in Sweden (as described in section 5.3.2 above).

5.4 Mercury concentrations in environmental media

418. Large amounts of data on mercury concentrations in various environmental media (air, water, soil, sediments) and biota (plants, animals and other living organisms) have been referenced in submissions to this assessment, as well as in the literature. For further detail, the reader is invited to consult, inter alia:

- Reports and data of the French Institute for Marine Research, available on their website http://www.ifremer.fr/envlit/surveillance/index.htm;
- Reports and data of the Arctic Monitoring and Assessment Programme (AMAP), available on their website http://www.amap.no/;
- Chapter 3 of Volume III of the US EPA Mercury Study Report to Congress (US EPA, 1997), available at http://www.epa.gov/airprogm/oar/mercury.html.

419. It would be very important to investigate and review all such available data, which would likely add to our understanding of the impact of mercury as a global pollutant, and could provide a baseline for monitoring. However, this has not been possible within the time and resource constraints imposed on UNEP’s global mercury assessment process. Therefore, the information submitted from different parts of the world on mercury concentrations in fish (see section 4.5) serves as an indicator illustrating the omnipresence of mercury in the global environment.

6 Sources and cycling of mercury to the global environment

6.1 Overview

420. The releases of mercury to the biosphere can be grouped in four categories:

- Natural sources - releases due to natural mobilisation of naturally occurring mercury from the Earth's crust, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of mercury impurities in raw materials such as fossil fuels – particularly coal, and to a lesser extent gas and oil – and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;
- Re-mobilisation of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles.

421. Figure 6.1 shows these release categories with main types of possible control mechanisms.

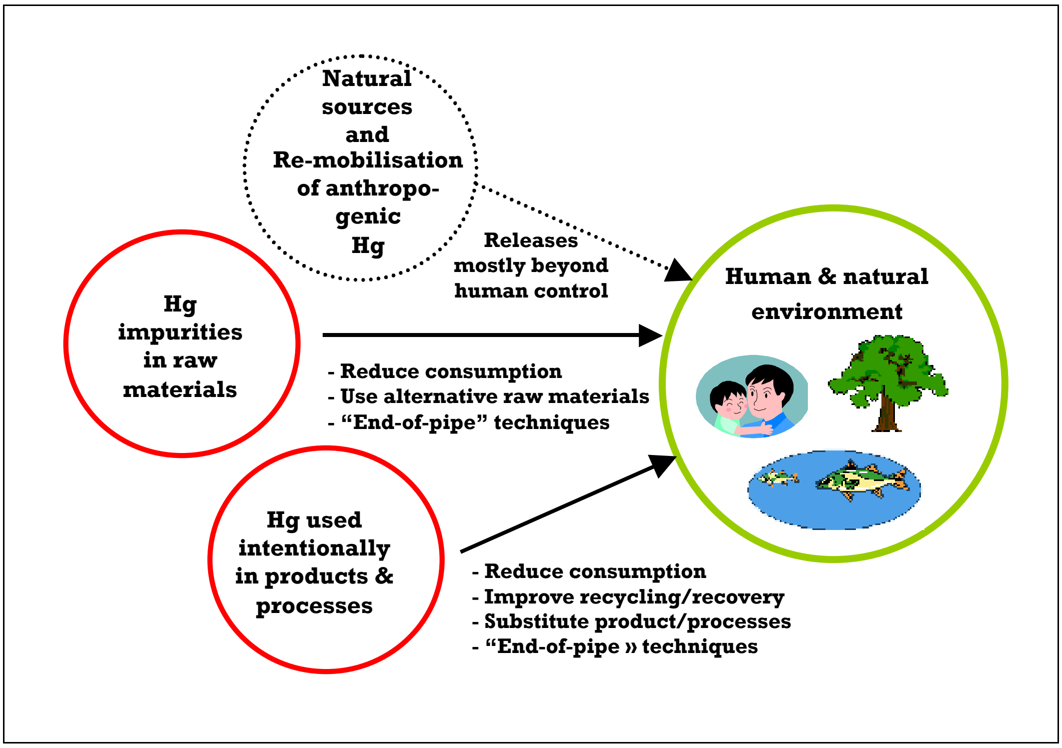


Figure 6.1 Categorisation of sources of mercury releases to the environment and main control options.

422. The recipients of mercury releases to the environment include the atmosphere, water environments (aquatic) and soil environments (terrestrial). There are continuing interactions – fluxes of mercury – between these compartments. These are described in section 6.4 on pathways of mercury to – and in – the environment. The speciation – the chemical form – of the released mercury varies depending on the source types and other factors as described in chapter 2. This also influences the impacts on human health and environment as different mercury species have different toxicity.

423. Given the understanding of the global mercury cycle, current releases add to the global pool of mercury in the biosphere – mercury that is continuously mobilised, deposited on land and water surfaces, and re-mobilised. Being an element, mercury is persistent – it cannot be broken down to less toxic substances in the environment. The only long-term sinks for removal of mercury from the biosphere are deep-sea sediments and, to a certain extent, controlled landfills, in cases, where the mercury is physio-chemically immobilised and remains undisturbed by anthropogenic or natural activity (climatic and geological). This also implies that even as the anthropogenic releases of mercury are gradually eliminated, decreases in some mercury concentrations – and related environmental improvements – will occur only slowly, most likely over several decades or longer. However, improvements may occur more quickly in specific locations or regions that are largely impacted by local or regional sources.

Local releases – global effects

424. The origins of atmospheric mercury deposition (flow of mercury from air to land and oceans) are local and regional as well as hemispherical or global. Several large studies have supported the conclusion that, in addition to local sources (such as chlor-alkali production, coal combustion and waste incineration facilities), the general background concentration of mercury in the global atmosphere contributes significantly to the mercury burden at most locations. Similarly, virtually any local source contributes to the background concentration – the global mercury pool in the biosphere - much of which represents anthropogenic releases accumulated over the decades (see for example US EPA, 1997; Munthe *et al.*, 2001). Also, the ocean currents are media for long-range mercury transport, and the oceans are important dynamic sinks of mercury in the global cycle.

425. The majority of atmospheric anthropogenic emissions are released as gaseous elemental mercury. This is capable of being transported over very long distances with the air masses. The remaining part of air emissions are in the form of gaseous divalent compounds (such as $HgCl_2$) or bound to particles present in the emission gas. These species have a shorter atmospheric lifetime than elemental vapour and will deposit via wet or dry processes within roughly 100 to 1000 kilometres. However, significant conversion between mercury species may occur during atmospheric transport, which will affect the transport distance.

426. The atmospheric residence time[4] of elemental mercury is in the range of months to roughly one year. This makes transport on a hemispherical scale possible and emissions in any continent can thus contribute to the deposition in other continents. For example, according to the modelling of the intercontinental mercury transport performed by EMEP/MSC-E (Travnikov and Ryaboshapko, 2002) up to 50 percent of anthropogenic mercury deposited to North America is from external sources. Similarly, contributions of external sources to anthropogenic mercury depositions to Europe and Asia were estimated to be about 20 percent and 15 percent, respectively.

427. Furthermore, as mentioned, mercury is also capable of re-emissions from water and soil surfaces. This process greatly enhances the overall residence time of mercury in the environment. Recent findings by Lindberg *et al*. (2001) indicate re-emission rates of approximately 20 percent over a two-year period, based on stable mercury isotope measurements in north-western Ontario, Canada.

Anthropogenic sources of mercury releases

428. A large portion of the mercury present in the atmosphere today is the result of many years of releases due to anthropogenic activities. The natural component of the total atmospheric burden is difficult to estimate, although a recent study (Munthe *et al.*, 2001) has suggested that anthropogenic activities have increased the overall levels of mercury in the atmosphere by roughly a factor of 3.

429. While there are some natural emissions of mercury from the earth's crust, anthropogenic sources are the major contributors to releases of mercury to the atmosphere, water and soil.

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[4] Atmospheric residence time here designates the time span from a given mercury molecule is emitted to the atmosphere till it is deposited (on land or in water). It does not include subsequent re-emission to the atmosphere.

Examples of important sources of anthropogenic releases of mercury

Releases from mobilisation of mercury impurities:

- Coal-fired power and heat production (largest single source to atmospheric emissions)
- Energy production from other fossil carbon fuels
- Cement production (mercury in lime)
- Mining and other metallurgic activities involving the extraction and processing of virgin and recycled mineral materials, for example production of:
  - iron and steel
  - ferromanganese
  - zinc
  - gold
  - other non-ferrous metals

Releases from intentional extraction and use of mercury:

- Mercury mining
- Small-scale gold and silver mining (amalgamation process)
- Chlor-alkali production
- Use of fluorescent lamps, instruments and dental amalgam fillings
- Manufacturing of products containing mercury, for example:
  - thermometers
  - manometers and other instruments
  - electrical and electronic switches

Releases from waste treatment, cremation etc. (originating from both impurities and intentional uses of mercury):

- Waste incineration (municipal, medical and hazardous wastes)
- Landfills
- Cremation and cemeteries (release to soil)

430. There are significant uncertainties in the available release inventories, not only by source, but also by country. Nonetheless, the best available estimates of mercury emissions to air from various significant sources are shown in table 6.1 below.

431. The emissions from stationary combustion of fossil fuels (especially coal) and incineration of waste materials accounts for approximately 70 percent of the total quantified atmospheric emissions from significant anthropogenic sources. As combustion of fossil fuels is increasing in order to meet the growing energy demands of both developing and developed nations, mercury emissions can be expected to increase accordingly in the absence of the deployment of control technologies or the use of alternative energy sources. Control technologies have been developed for coal combustion plants and waste incinerators with the primary intention of addressing acidifying substances (especially SO_2 and NO_x), and particulate matter (PM). Such existing technologies may provide some level of mercury control, but when viewed at the global level, currently these controls result in only a small reduction of mercury from these sources. Many control technologies are significantly less effective at reducing emissions of elemental mercury compared to other forms. Optimised technologies for mercury control are being developed and demonstrated, but are not yet commercially deployed.

432. Available global estimates of atmospheric emissions from waste incineration, as well as other releases originating from intentional uses of mercury in processes and products, are deemed underestimated and to some degree incomplete. However, recorded virgin mercury production has been decreasing from about 6000 to about 2000 metric tons per year during the last two decades, and consequently, related releases from mining and usage of mercury may also be declining.

433. Anthropogenic emissions from a number of major sources have decreased during the last decade in North America and Europe due to reduction efforts. Also, total anthropogenic emissions to air have been declining in some developed countries in the last decade. For example, Canadian emissions

were reduced from about 33 metric tons to 6 metric tons between 1990 and 2000 (Canadian comments, comm-20-gov; Canadian submission, sub42gov).

Table 6.1 Estimates of global atmospheric releases of mercury from a number of significant anthropogenic sources in 1995 (metric tons/year). Releases to other media are not accounted for here. ****1***

Continent	**Stationary combustion**	**Non-ferrous metal production *5**	**Pig iron and steel production**	**Cement production**	**Waste disposal *2**	**Artisanal gold mining *4**	**Sum, quantified sources *3**
Europe	186	15	10	26	12		250
Africa	197	7.9	0.5	5.2			210
Asia	**860**	**87**	**12**	**82**	33		1070
North America	105	25	4.6	13	**66**		210
South America	27	25	1.4	5.5			60
Australia and Oceania	100	4.4	0.3	0.8	0.1		100
Sum, quantified sources, 1995 ***3,4**	1470	170	30	130	110	300	1900 +300
Based on references:	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Lacerda (1997)	

Notes: 1 Releases to aquatic and terrestrial environments, as well as atmospheric releases from a number of other sources, are not included in the table, as no recent global estimates are available. See chapter 6 for description of issue.

2 Considered underestimated by authors of the inventory, see notes to table 6.10.

3 Represents total of the sources mentioned in this table, not all known sources. Sums are rounded and may therefore not sum up precisely.

4 Estimated emissions from artisanal gold mining refer to late 1980's/early 1990's situation. A newer reference (MMSD, 2002) indicates that mercury consumption for artisanal gold mining - and thereby most likely also mercury releases - may be even higher than presented here.

5 Production of non-ferrous metals releasing mercury, including mercury, zinc, gold, lead, copper, nickel.

Natural sources of mercury release

434. Natural sources include volcanoes, evaporation from soil and water surfaces, degradation of minerals and forest fires. The natural mercury emissions are beyond our control, and must be considered part of our local and global living environment. It is necessary to keep this source in mind, however, as it does contribute to the environmental levels. In some areas of the world, the mercury concentrations in the Earth's crust are naturally elevated, and contribute to elevated local and regional mercury concentrations in those areas.

435. Today's emissions of mercury from soil and water surfaces are composed of both natural sources and re-emission of previous deposition of mercury from both anthropogenic and natural sources. This makes it very difficult to determine the actual natural mercury emissions. For global estimates of natural emissions, see section 6.3.6.

436. Published estimates of natural versus anthropogenic mercury emissions show significant variation, although more recent efforts have emphasized the importance of human contributions (see for example Fitzgerald *et al.* (1998), Jackson (1997) and Lamborg *et al.* (2002)). Attempts to directly measure natural emissions are ongoing (see for example Coolbaugh *et al.*, 2002). Nonetheless, available information indicates that natural sources account for less than 50 percent of the total releases.

437. On average around the globe, there are indications that anthropogenic emissions of mercury have resulted in deposition rates today that are 1.5 to 3 times higher than those during pre-industrial times. In and around industrial areas the deposition rates have increased by 2 to 10 times during the last 200 years (Lindquist *et al.*, 1984; Bergan *et al.*, 1999; see also section 6.4 on pathways).

Contributions from intentional uses versus impurities in high volume materials

438. Regarding anthropogenic releases, the relative importance of intentional uses versus mobilisation of mercury impurities varies between countries and regions, particularly depending on:

- State of substitution of intentional uses (products and processes);
- Reliance on fossil fuels for energy production, particularly coal, and the presence of controls for other pollutants, which also reduce mercury emissions;
- Extent of mining and mineral extraction industry;
- Waste disposal pattern – incineration/landfilling;
- State of implementation of release control technologies in power production, waste incineration and various industrial processes.

439. For a number of countries described in the submission from the Nordic Council of Ministers (sub84gov), estimated contributions of intentional uses vary between 10 and 80 percent of the total domestic emissions to air, depending on the influence of the factors listed above in each country. Rough estimates by main anthropogenic source types in each of these countries are shown in section 6.3.2.

440. As an illustration, figure 6.2 shows the overall turnover of mercury in the Danish society in 1992/93. Denmark is a quite small country with relatively accurate monitoring of the flows of products and waste in the economy and the environment. Therefore, it has been possible to perform rather detailed balances, so-called substance flow assessments for mercury, which provide useful information on the contributions from different sectors to the total mercury burden in the society and the environment. As shown in the figure, the majority of the input – more than two thirds – originated from intentional uses (chlor-alkali production and products), and the contributions from intentional uses to releases to air in 1992/93[5] could roughly be estimated at 50-80 percent of the total releases to air from Denmark (submission from the Nordic Council of Ministers, sub84-gov). It should be noted that primary mineral extraction and processing is not as large a sector in Denmark, as in many other countries.

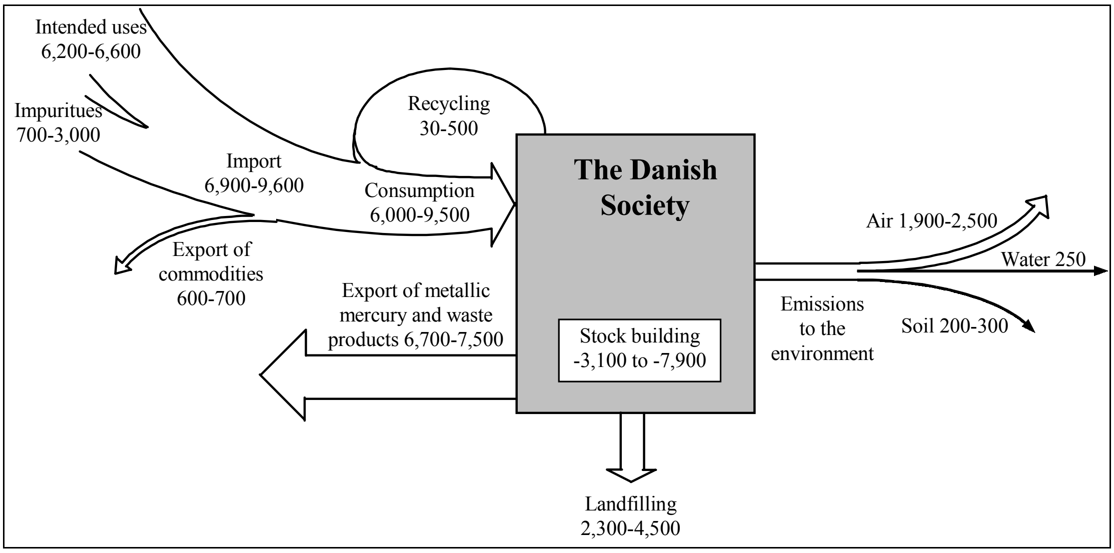

Figure 6.2 The turnover of mercury in the Danish society in 1992/93, kilograms mercury/year (based on Maag et al.*, 1996). Please note that inputs and outputs do not balance because outputs reflect higher inputs from previous years. Net change in stocks was negative.*

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[5] The source (submission from the Nordic Council of Ministers, sub84gov) notes that since 1992/93 the consumption of mercury with intentional uses in Denmark has decreased further and emission reduction from coal-fired power plants and waste incineration has been enhanced further by improvements in exhaust gas cleaning.

441. Examples of national distributions of anthropogenic mercury releases from different individual source types are given in section 6.3.4. In countries where mercury mining or intentional use of mercury for small-scale gold mining is taking place, these sources can be significant (see for example Colombian submission, sub14gov).

442. Parts of the descriptive text in this chapter were based on the submission from the Nordic Council of Ministers (sub84gov) and to a lesser extent Pirrone *et al.* (2001).

6.2 Natural sources of mercury

443. Natural sources include volcanoes, evaporation from soil and water surfaces, degradation of minerals and forest fires. Mercury in small, but varying concentrations can be found virtually in all geological media. Elemental and some forms of oxidized mercury are permanently coming to the atmosphere due to their volatility. High temperature in the Earth mantle results in high mercury mobility and mercury continuously diffuses to the surface. In the zones of deep geological fractures these processes go on more intensively. Here are located so-called mercury geochemical belts where mercury concentrations in the upper layer appreciably exceed their average values. In some parts of mercury belts the intensive accumulation of mercury resulted in the formation of (extractable) deposits (Jonasson and Boyle, 1971; Bailey *et al.*, 1973). Regions with high concentrations in surface rocks are characterized by high mercury emissions to the atmosphere.

444. Today's releases of mercury from soil and water surfaces are, however, not only natural, but are significantly influenced by previous deposition of mercury from anthropogenic sources. This makes it extremely difficult to determine the actual natural mercury emissions. For example, total estimates of re-emission from soil and water surfaces in Europe exist, but they include mercury originating from both natural and anthropogenic sources (Pirrone *et al.*, 2001).

445. A considerable portion of the mercury emissions from forest fires may also be re-emitted anthropogenic mercury (USA; comm-24-gov).

446. A number of attempts have been made to estimate the regional and global natural emissions of mercury. It is, however, difficult to do so with any precision and research is still done in this field at several institutions (AMAP, 2000).

447. Understanding of the global mercury cycle, shown schematically in figure 6.3, has improved significantly with continuing study of source releases, mercury fluxes to the earth's surface, and the magnitude of mercury reservoirs that have accumulated in soils, watersheds and ocean waters. Although considerable uncertainty still exists, it has become increasingly evident that anthropogenic emissions of mercury to the air rival or exceed natural inputs. Recent estimates place the annual amounts of mercury released into the air by human activities at between 50 and 75 percent of the total yearly input to the atmosphere from all sources (US EPA, 1997).

448. Mason *et al.* (1994) estimated the global natural emissions at about 1650 metric tons/year. In an update performed by Lamborg *et al.* (2002) it was estimated at 1400 metric tons/year (as illustrated in figure 6.3). MSC-E and EMEP (comm-4-ngo) quote Bergan and Rohde (2001) for an estimated global natural emission of about 2400 metric tons, of which 1320 was emitted from land and 1100 was emitted from oceans.

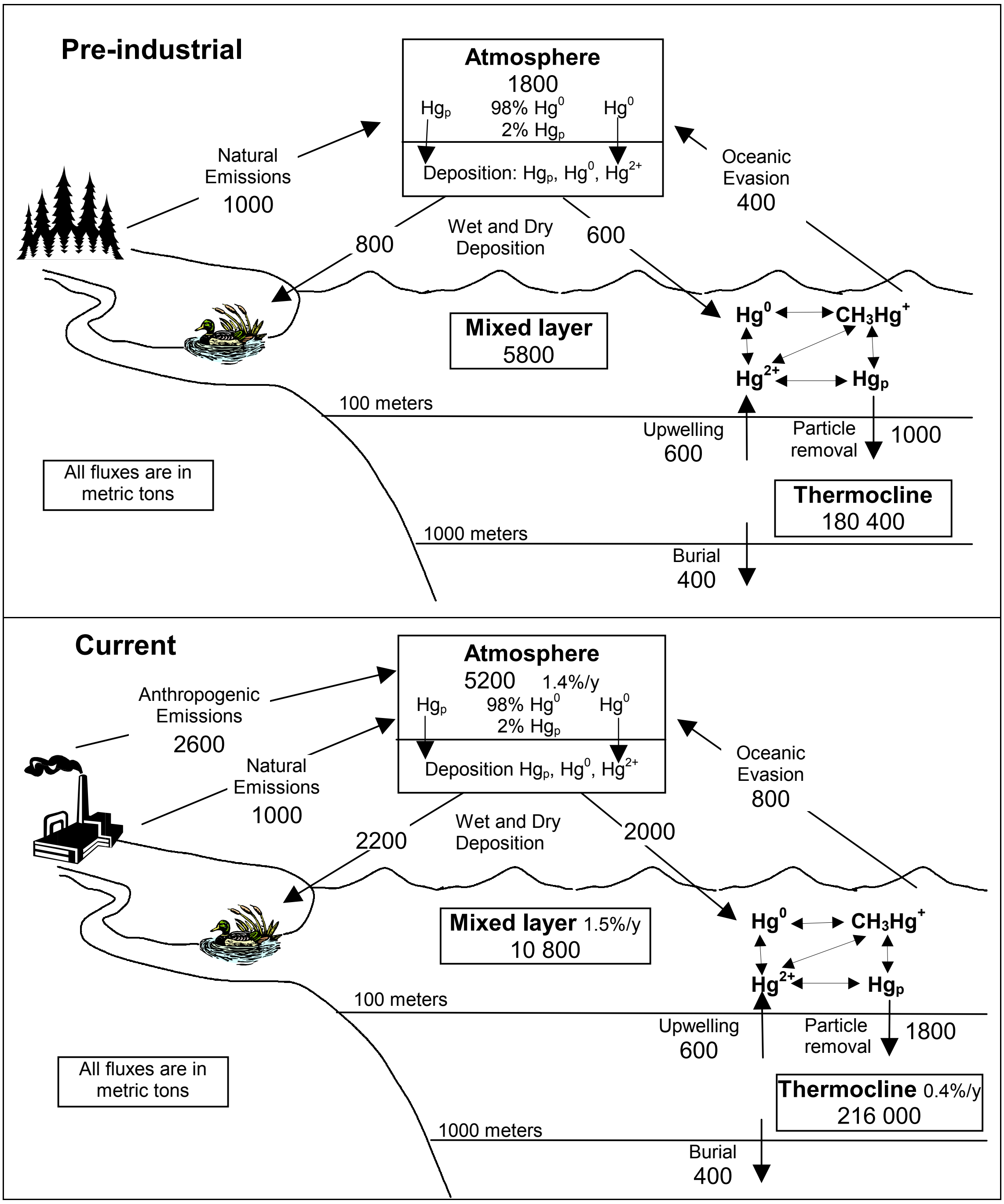

Figure 6.3 Comparison of estimated pre-industrial and current mercury budgets and fluxes. All fluxes (arrows) and pools (in frames) in metric tons (adapted from Lamborg et al. (2002); the original authors note that the cycle is seen as unsteady.)

6.3 Anthropogenic sources of mercury

6.3.1 Mobilisation of mercury impurities in materials

449. Mercury is naturally present in coal and other fossil fuels, as well as in minerals like lime for cement production and soils (such as agricultural soils subject to acidification management) and metal ores including for example zinc-, copper- and gold ore. Coal-fired power production is today deemed the single largest global source of atmospheric mercury emissions (Pacyna and Pacyna, 2000). This is due to the increasing global power consumption, and also to the fact that emissions from intentional use of mercury are gradually diminishing in many of the industrialised countries.

450. As an example, China reports the following regarding the emissions of mercury from coal combustion in the country:

> "According to information from research, the average mercury content of coal is 0.038 – 0.32 mg/kg. The total amount of mercury emissions from coal combustion was about 296-302.9 metric tons annually in the middle of the 1990's, including 213.8 metric tons in the atmosphere and 89.07 metric tons in ash and cinder. The average content of organic mercury in coals collected from 15 provinces and cities was 0.037 mg/kg, occupying 18.1 percent of the mercury. The average contents of organic mercury in fly ashes of burning coal 0.045 mg/kg, occupying 28.1 percent of total mercury in ash. From 1978 through 1995, mercury emission had been increasing at average 4.8 percent per year." (Comments from China, comm-19-gov).

451. When relating this information to estimates of global mercury emissions from major quantified sources (approx. 2100 metric tons/year in 1990), as shown in table 6.11, it is clear that the importance of emissions from coal combustion is significant.

452. Mercury impurities in primary and recycled materials constitute major contributions to the total global mercury burden. Measures to reduce these releases are described in chapter 8.

453. Processing of secondary raw materials, like iron and steel for example, can also be a significant source of mercury releases, and emission control technologies are often necessary. In this case the origin of the mercury may be both natural impurities and a result of intentional use of mercury in products/components in iron/steel scrap (switches, air-bag activators etc.)

454. Many industrialised countries have legislative structures for emission control covering mercury in place today. The national submissions to UNEP for this assessment indicate that the situation might be different for a number of countries with other conditions, see chapter 9 and the separate Appendix to this report – Overview of existing and future national actions, including legislation, relevant to mercury.

6.3.2 Releases from intentional use of mercury in products and processes

455. As described in chapter 7, mercury is used in many products and industrial processes. Despite decreasing consumption in many industrialised countries during the last two decades, the intentional use of mercury in products and processes is still deemed a significant source of mercury to the environment. The recorded global primary production of virgin mercury is still large compared to current estimates of global atmospheric mercury emissions.

456. When assessing the releases of mercury to the environment, it is generally difficult to quantify diffuse releases from the life cycle of mercury-containing products. These sources have not always been included fully in regional or global inventories for mercury releases to the environment. Some national studies do however give a certain insight in the contributions from this source category (see below).

457. The releases of mercury from waste treatment and storage can be very difficult to assess, but national balances ("substance flow assessments") can cast light on some of the aspects needed. Such substance flow assessments have been performed with varying detail in for example the Netherlands, USA and Denmark.

458. Also, some research performed in the US indicates that releases from products via normal use, spills, breakage, scrap metal processing and disposal are significant sources that may be underestimated in some release inventories (USA; comm-24-gov).

459. Much of the mercury brought into use with products and for consumer purposes will be incinerated or end up in landfills with collected waste. In many parts of the world it may be lost, dumped or incinerated diffusely and informally directly in the environment. Under present circumstances, therefore, a significant part of the total consumption of mercury is expected to end up in the environment rather directly and quickly. How much this amounts to on a global level has not been seriously esti-

mated. As indicated in section 6.4 on pathways, some of the mercury used, collected and treated under more controlled conditions may also be spread to the environment over a longer period of time.

460. Examples of quantified contributions from different intentional uses to national mercury releases are given in section 6.3.4 below.

Relative importance to air emissions of intentional uses versus impurities

461. When considering the abatement measures to choose, it is relevant to examine the relative importance of intentional mercury uses versus mercury impurities in materials. This poses some difficulties, as not all flows are registered in detail, and particularly as the origin of mercury in the waste flow cannot always be allocated with precision. Nevertheless, it is possible to form rough impressions of this relationship in individual countries, notably where substance flow assessments (SFAs) on mercury have been performed. In table 6.2, rough estimates of the distribution of air emissions on main source categories are presented on the basis of the data presented in this section. In the table, note that releases to water and soil are not included, but may be of significance. Landfilled amounts are not included, except for some recorded air emissions from landfills. Additionally, inventory methodology may vary among the countries and not all emissions are necessarily recorded in all cases.

462. The contribution from intentional mercury uses in a number of products in the European region was also assessed by Munthe and Kindbom (1997). They found that in the mid-1990's three dominating groups of intentional mercury uses in products[6] contributed about 18 percent of the total mercury emissions to air in this region. Additional contributions from dental amalgam use were not included in the assessment.

463. See also the discussion of relative importance of main source categories, and factors influencing this distribution, in section 6.1.

Table 6.2 Rough estimates of relative importance of main source categories to recorded anthropogenic emissions to air – examples (submission of the Nordic Council of Ministers, sub84gov).

Relative importance of source categories to recorded anthropogenic emissions to air – examples			
Country, year	**% of total recorded national anthropogenic emissions to air** (rough estimates) ***1**		**Comments**
	Hg from impurities	**Hg from intentional uses**	
USA, 1994/95	60 – 90	10 – 40	34% are emitted from waste treatment - original sources hereof are not accounted for in detail
UK, 1997	60 – 80	20 – 40	13% from waste treatment - original sources hereof are not accounted for in detail
Denmark, 1992/93	20 – 50	50 – 80	58% from waste treatment - some details regarding sources to waste available for estimation - see also description above
Sweden, 1995	40 – 60	40 – 60	10% from waste treatment - original sources hereof are not accounted for in detail
Norway, 1999	80 – 90	10 – 20	5% from waste treatment – original sources hereof are not accounted for in detail
1: Inventory methodology varies among countries. Not all emissions are necessarily recorded in all cases. Releases to water and soil are not included, but may be of significance. Landfilled amounts are not included, except for some recorded air emissions from landfills.			

Note: Data sources mentioned in table 6.4 in section 6.3.4.

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[6] Batteries, measuring and control instruments, and lighting and electrical equipment, which together constituted a major share of mercury consumption with products in the mid-1990's, although the emissions due to batteries, in particular, have been substantially reduced in some regions since that time. Numbers from the countries described in this report indicate that particularly dental amalgam adds significantly to the emissions from products.

464. Table 6.3 from US EPA (1997) shows estimates/projections for US discards of mercury used intentionally in products. For comparison, the reported consumption of mercury with intentional uses in the USA was estimated at 711 metric tons in 1990 and 372 metric tons in 1996 (Sznopek and Goonan, 2000; corresponding to 784 and 410 short tons respectively). It should be noted that mercury contents in waste products reflect earlier, higher mercury consumption rates (see figure 9.2 in section 9.2.4 UNITED STATES).

465. According to new information from the USA (comm-24-gov), table 6.3 may not account for the use of mercury switches in cars, or may undercount estimated discards in the USA. The State of Maine's Department of Environmental Protection estimates an average of roughly 2/3 switch per car on the road today, at 0.8 grams of mercury per switch. While it is true that these switches do not typically wind up in MSW disposal facilities per se, they are largely discards from households and are unaccounted for in typical product discard inventories such as table 6.3.

Table 6.3 Estimated discards of mercury used intentionally in products in municipal solid waste in the USA as estimated/projected in 1992[a], unless noted (US EPA, 1997).

Products (amounts in metric tons)	**1975**	**1980**	**1985**	**1989**	**1995**	**2000**
Batteries						
Alkaline	34.8	143.5	319.5	380.4	*	18.1 d
Mercuric oxide	261.0	242.0	213.3	178.3	*	5.4 d *
Others	4.3	4.1	4.1	4.7	*	0.0
Subtotal Batteries	300.1	389.6	536.9	563.4	*	23.6 d *
Electric Lighting						
Fluorescent Lamps	19.5	21.0	25.3	21.3 d	22.5 d	13.2 d
High Intensity Lamps	0.3	1.0	0.6	0.7	0.9	1.1
Subtotal Lighting	19.8	22.0	25.9	22.0 d	23.4 d	14.2 d
Paint Residues	33.8	24.2	28.5	16.5	2.1	0.5
Fever Thermometers	21.0	23.3	29.5	14.8	15.3	15.2
Thermostats	6.2	6.3	8.6	10.2	7.3	9.3
Pigments	24.9	20.9	22.9	9.1	2.7	1.4
Dental Uses	8.8	6.4	5.6	3.6	2.6	2.1
Special Paper Coating	0.5	1.1	1.6	0.9	0.0	0.0
Mercury Light Switches	0.4	0.4	0.4	0.4	0.4 d	0.3 d
Film Pack Batteries	2.1	2.4	2.5	0.0	0.0	0.0
Total Discards	417.7	496.6	662.5	640..9 d	215.6 d	145,2 d

Notes:

[a] US EPA, 1992 (except for fluorescent lamps estimates).

[b] Discards before recovery.

[d] New information from the USA (in comm-24-gov, 2002).

* Since 1992 several States have restricted the mercury content of alkaline batteries and/or banned the sale of mercuric oxide batteries. Federal legislation to restrict mercury use in batteries went into effect in May 1996. The battery industry has eliminated mercury as an intentional additive in alkaline batteries, except in button cells. Although no current estimate of mercury releases from batteries was available for these years, according to the National Electrical Manufacturers Association (NEMA), the entire USA battery industry used only approximately 6.6 tons of mercury in 1994 (NEMA, 1996).

6.3.3 Mobilisation of mercury due to changes in land use

466. Under some conditions anthropogenic changes in land use may result in substantial mobilisation of mercury already present in the environment (originating from natural and/or anthropogenic sources). For example, in some environments, anthropogenic modifications including farmlands, recent clear-cuttings and water reservoirs (hydroelectric, aquaculture, irrigation) may considerably enhance the release of mercury to aquatic systems and the bio-accumulation of mercury in organisms. There is a growing body of evidence that the soils of forested watersheds contain considerable stores of both methylmercury and inorganic divalent forms. Both in North America and in Northern Europe, evidence is gradually accumulating, which points to the effect of terrain disturbance as a factor in the mobilisation and transport of both the inorganic and methylmercury stored in watersheds, and apparently also in the production of methylmercury. Investigations in connection with hydro-electric reservoirs revealed the importance of understanding transport phenomena involving flooded soils. Watershed-scale hydrology is emerging as an increasingly important explanatory variable (Canadian comments; comm-20-gov).

6.3.4 Examples of national mercury releases distributed on source types

467. As mentioned above, the relative contributions to releases of mercury from different source types varies between countries depending on a number of factors. In order to illustrate possible loads from individual source types, examples of distributions of releases to air, water, soil and landfills are given for a number of countries in tables 6.4-6.7 below (aggregated in the submission from the Nordic Council of Ministers, sub84gov, except for Mexican data added here).

468. Attention must be paid to the often significant differences between countries, which again are related to differences with respect to the sources that exist, different equipment or standards for cleaning operations like flue gas cleaning, as well as different year and methodology of investigation. Though a deeper investigation and description of the background and quality of the presented data would be useful, this has not been possible for this report, principally due to limitations in time and resources. This also implies that direct comparison between countries is not relevant.

469. The countries mentioned in the following three tables were chosen as illustrative examples only. A number of other countries also regularly collect and publish release data and a number of data sets were submitted by other countries. These can be found in national submissions and comments available on the Global Mercury Assessment webpage www.chem.unep.ch/mercury.

470. An important source of mercury releases that is not covered in the tables given in this section, but which is occurring in an increasing number of countries, is the use of mercury for gold and silver extraction. Based on available - and probably incomplete - information, it has been estimated that the present annual global mercury input to the environment from gold mining alone may be upwards of 500 metric tons, two-thirds of it emitted to the atmosphere, with the other third going to soils and waters (Lacerda, 1997; MMSD, 2002). Similarly, in those countries where primary mercury is still mined, this mining may also represent a significant source of mercury releases.

471. It should be noted that relatively few data are available regarding the releases of mercury on the total life cycle of oil and natural gas (from extraction to combustion or disposal). Both are consumed in large quantities globally. Additional research on this important question is ongoing in the USA and scheduled for reporting in 2003 (USA, comm-24-gov).

472. Thailand has described their efforts in the management of mercury releases to the aquatic environment from oil and gas extraction (Thai submission, sub53gov).

Emissions to the atmosphere

473. Besides the sources mentioned above, important sources for atmospheric emissions include certain industrial activities, waste treatment and disposal, as well as combustion and fossil fuel energy generating processes in general.

474. Combustion of waste is a major source of mercury releases to the environment. It should be kept in mind, that the source of this mercury is the mercury contents in the products constituting the waste, both in the form of intentionally used mercury and unintentional presence of mercury (either as a natural impurity or as an anthropogenic trace pollutant in the raw materials used).

475. Concerning cremation, it may be noted that crematories are normally not equipped with flue gas cleaning facilities for removal of mercury. The emissions from cremation are primarily due to the use of mercury in amalgam for dental purposes.

*Table 6.4 Mercury emissions to air - examples ***1***

All numbers in metric tons/year (except per capita)	**USA *7 1994-95**	**UK 1997**	**Finland 1997**	**Denmark 1992-93**	**Sweden 1995**	**Norway 1999**	**Mexico 1999**
Intentional uses – Manufacturing		1.1*8	*4				
Chlor-alkali	6.5			0.01	0.12		4.9
Instruments manufacturing	0.5						
Secondary Hg production	0.4						
Electrical apparatus	0.3			0.01			
Batteries	<0.1						
Primary mercury production	?						9.7
Intentional uses – Use of products							
Lamps breakage	1.4	<0.1				0.02	0.23
Laboratory use and instruments	1.0					0.02	0.02
Dental preparations	0.6	0.3					0.38
Waste treatment and disposal			0.05				
Waste incineration *2	48.8	1.3		1.26 *5	0.09	0.05	0.03
Cremation	<0.1	1.3		0.1	0.28	0.07	
Landfills	<0.1	0.4					
Others – recycling of lamps etc.	<0.1			0.2	0.01		
Mobilised Hg impurities – Manufacturing			0.09 *4				
Cement	4.4			0.14		0.01	0.01
Pulp and Paper	1.7					0.005	0.02
Non-ferrous metal	<0.2	3.2			0.07	0.16	13
Iron, steel		0.8		0.07	0.11	0.1	0.09
Others – carbon black, lime etc.	0.4?					0.005	0.76
Mobilised Hg impurities – Combustion		4.2	0.49		0.21	0.64	2.2 *6
Coal (utility, industry) boilers	66.9			0.35			
Oil and natural gas	10.2			0.04			
Wood boilers	0.2						
Others (geothermal power)	1.3						
Total (rounded)	144 *7	13	0.62	2.2	0.9	1.1	31
Per capita (grams) *3	0.5	0.2	0.1	0.4	0.1	0.3	0.3

Notes:

1 From US EPA (1997); OSPAR (2000); Maag *et al.* (1996); Norwegian Pollution Control Authority (2001); Finnish Environment Institute (1999); Mukherjee *et al.* (2000); Mexican information submission, and KEMI (1998). The presented distribution of sources, as intentional/unintentional, was made in the submission from the Nordic Council of Ministers (sub84gov), except for Mexican numbers.

2 Covers incineration of municipal waste, medical waste, hazardous waste and sewage sludge.

3 Assumptions USA ~ 264 million capita; UK ~ 59 million capita; Denmark ~ 5.3 million capita; Norway ~ 4.4 million capita; Sweden ~ 8.5 million capita; Finland ~ 5.2 million capita; Mexico ~ 99 million capita.

4 In the reference (Mukherjee *et al*, 2000), emissions from manufacturing are aggregated and include both mercury from unintentional mobilisation and intentional uses. There are indications, however, that the first mentioned is the dominating source category from manufacturing. Total emissions from manufacturing are therefore mentioned under "Mobilised Hg impurities – Manufacturing".

5 The relatively high figure for waste incineration in Denmark in 1992-93 was caused by the widespread use of incineration for treatment for municipal solid waste in the country. In 1993, around 78 percent of all municipal solid waste in Denmark was di-

rected to incineration, and at that time only 86 percent of the incineration capacity was equipped with cleaning facilities for acidic flue gas cleaning (Maag *et al*, 1996).

6 Categorised in Mexican submission as follows: thermo-electric plants (0.13 metric tons/y), carbo-electric plants (0.79), industrial commercial boilers (0.095) and residential wood combustion (1.2 metric tons/y).

7 The USA (in comm-24-gov) provided updated information on national emissions from certain source categories and totals (1996 emissions in metric tons): Chlor-alkali: 9, lamps breakage: 1, dental preparation: 0.7, waste incineration: 74, landfills: 0.2, Cement: 4, pulp and paper: 2, coal boilers: 55 (uncertain), oil and natural gas: 1, and total quantified emissions for 1996: 170. For 1999 the total quantified emissions were estimated at 125 metric tons.

8 According to OSPAR (2001b, as cited by Greenpeace), the chlor-alkali industry in the United Kingdom reported mercury releases of 1.4 metric tons in 1999.

Releases to water

476. Concerning releases to water a dominant source in western countries will typically be outlets from municipal sewage treatment plants, as municipal wastewater may contain mercury originating from e.g. dentist clinics, miscellaneous measurement and monitoring equipment as well as laboratories (originating from intentional uses). In some countries, direct discharges of mercury-containing wastewater may be relatively larger. Also, several other sources of mercury releases to aquatic environments are not listed in the table below, and the quantities may not reflect the situation in countries with less developed controls. This may particularly be the case if a country has large industrial sectors applying mercury, such as chlor-alkali production with mercury-cell technology.

477. The Norwegian data indicate that offshore oil activities may be a significant source of releases to the marine environment. A similar release may also likely take place into Danish waters (and possibly other locations), but has so far not been quantified.

*Table 6.5 Mercury releases to water – examples ***1***

	Denmark 1992-93 metric tons/year	**Sweden 1995 metric tons/year**	**Norway 1998-1999 metric tons/year**
Intentional uses – Manufacturing			
Chlor-alkali	<0.001		
Intentional uses - Use of products			0.05
Waste treatment and disposal			
Municipal sewage treatment	0.25 2)	0.53	0.06
Other			0.04
Mobilised Hg impurities – Manufacturing			
Non-ferrous metal		0.02	0.03
Others – refineries, offshore etc.		0.02	0.17
Total	0.25	0.74	0.35
Per capita (g) *2	0.05	0.09	0.08

Notes:

1 From Maag *et al.* (1996), Norwegian Pollution Control Authority (2001) and KEMI (1998). Presented distribution of sources as intentional or unintentional was made in the submission from the Nordic Council of Ministers (sub84gov).

2 Assumptions: Denmark ~ 5.3 million capita; Norway ~ 4.4 million capita; Sweden ~ 8.5 million capita.

Releases to soil

478. Concerning releases to soil in the examples from the Nordic countries, the dominant sources seem to be:

- Cemeteries, which is primarily due to the use of mercury as amalgam for dental purposes; and
- Land application of sewage sludge from municipal wastewater treatment (originating from intentional uses as described).

*Table 6.6 Mercury releases to soil - examples ***1***

	Denmark 1992-93 metric tons/year	**Norway 1999 metric tons/year**
Intentional uses – Manufacturing		
Intentional uses - Use of products		
Cemeteries (dental amalgam)	0.05	0.17
Others		?
Waste treatment and disposal		
Sewage sludge	0.14	0.14
Other	?	
Mobilised Hg impurities – use of products		
Fertilizer/lime – agricultural purposes	<0.1	0.003
Total	0.25?	0.31
Per capita (g) *2	0.05	0.07

Notes: From Maag *et al.* (1996) and Norwegian Pollution Control Authority (2001). Distribution of sources as intentional or unintentional is the responsibility of the authors of this report solely.
Assumptions: Denmark ~ 5.3 million capita; Norway ~ 4.4 mil capita.

6.3.5 Landfilling

479. Besides the direct releases to the environment indicated above significant quantities of mercury are directed to landfills either as manufacturing waste, end-of-pipe technology waste or contained in products disposed of as municipal solid waste or hazardous waste.

480. Information on mercury quantities landfilled in a number of countries is presented in table 6.7. The noted differences between countries may be explained by:

- Different activities, e.g. whether mining and metal extraction takes place in the country or not;
- Different environmental policies, e.g. mercury is extracted from zinc extraction residues in Finland, whereas in Norway such residues are directed to landfill;
- The sources included may differ between inventories.

*Table 6.7 Mercury directed to landfills or collected as hazardous waste (aggregated in the submission from the Nordic Council of Ministers, sub84gov) ***1**.*

Country	**To landfills**		**Comments**
	Total metric tons/year	**Per capita g/year *2**	
UK ~1990	41	0.69	
Denmark 1997	2.5	0.47	Not including waste exported for special disposal in other countries
Finland ~1995	0.9	0.2	
Norway 1998	177	40	Mainly manufacturing waste from zinc extraction. The figures are from 1993. In 2000 the total amount was in the range of 35 metric tons/year ***3**
Sweden ~1995	42	4.9	Mainly mining waste
USA 1996	295	1.1	Including land application

Notes:
1 Original references: Sznopek & Goonan 2000, OSPAR 2000, Endre *et al.*, 1999.
2 Assumptions USA ~ 264 million capita; UK ~ 59 million capita; Denmark ~ 5.3 million capita; Finland ~ 4.8 million capita; Norway ~ 4.4 million capita; Sweden ~ 8.5 million capita.
3 Reference: Norwegian Pollution Control Authority (2001).

6.3.6 Global and regional release estimates

481. The total global anthropogenic and natural releases of mercury are not known with high precision. Several attempts have been made, however, at quantifying these totals. Table 6.8 shows global totals as estimated by different authors. As can be seen, the numbers are relatively uncertain. This is reasonable given the complexity of the quantification. As mentioned in section 6.3.7, generally it has not been possible to include all significant contributions to global releases in the estimates. An impression of which source types may be included and which may often be omitted can be seen in table 6.9.

Table 6.8 Estimates of total releases of mercury to the global environment (table presented by OECD, 1994, with estimates by Mason et al. *(1994), Pirrone* et al. *(1996) and Lamborg* et al. *(2002) added here).*

Process	**Lindquist *et al.* 1984**	**Nriagu & Pacyna 1988,Nriagu 1989**	**Fitzgerald 1986**	**Lindquist *et al.* 1991**	**Mason *et al.*, 1994 *1**	**Pirrone *et al.*, 1996**	**Lamborg *et al.*, 2002 *2**
Anthropogenic releases	2000-10,000	3560 (910-6200)	2000	4500 (3000-6000)	5550 ***1**	2200	3000 ***2**
Natural releases	<15000	2500 (100-4900)	3000-4000	3000 (2000-9000)	1650	2700	1400
Total present releases	2000-<25,000	6060 (1010-11,100)	5000-6000	7500 (5000-15,000)	7200	4900	4400

Notes: 1 Anthropogenic releases and totals: Numbers include an estimated re-emission (net increase of evasion from oceans) of 1400 metric tons/year originating from previous anthropogenic releases (new anthropogenic releases are thus estimated at 4150 metric tons/year in this study).

2 Anthropogenic releases and totals: Numbers include an estimated re-emission (net increase of evasion from oceans) of 400 metric tons/year originating from previous anthropogenic releases (new anthropogenic releases are thus estimated at 2600 metric tons/year in this study).

Table 6.9 Estimates of Worldwide Releases of Mercury to the Atmosphere, Soil and Water in 1983 with quantified and omitted contributions stated (metric tons per year, from Nriagu and Pacyna (1988) and Nriagu (1989) as presented by OECD (1994), presentation of summation slightly corrected and question marks added here).

Source category	**Atmosphere * min. max.**	**Water min. max.**	**Soil ** min. max.**
Coal combustion	650 3500	0 3600	370 4800
Non-ferrous metal production	45 220	0 40	0 80
Refuse incineration		no estimate	no estimate
Municipal	140 2100		
Sewage sludge	15 60		
Wastewater	no relevance	0 600	10 800
Wood combustion	60 300	no estimate	no estimate
Metal mining	insignificant input?	0 150	no estimate
Urban refuse	no estimate	no estimate	0 260
Wastage commercial prod.	no estimate	no estimate	550 820
Manufacturing processes	no estimate	20 2300	no estimate
Atmospheric fall-out	no relevance	220 1800	630 4300
Phosphate fertilizer production and use	insignificant input	no estimate	no estimate
Agricultural waste	no estimate	no estimate	0 1700
Logging and other wood wastes	no estimate	no estimate	0 2200
Dumpings of sewage sludge	no relevance	10 310	no relevance
Mine tailings	no estimate	no estimate	550 2800
Smelter slags and wastes	no estimate	no estimate	50 280
Total, quantified anthropogenic inputs, rounded	900 6200+?	300 8800+?	2200 18000+?
Mean	3560+?	4600+?	10100+?
Natural	100 4900	no estimate	No estimate
Mean	2500		

Notes: +? means that real totals may be larger, as inputs given as "no estimate" are not included in presented totals.

Notes in OECD (1994):

* Insignificant contributions to the atmosphere from: oil combustion, zinc-cadmium production, secondary non-ferrous production, steel and iron manufacturing, cement production, and mobile sources (eds. comment here: These input may actually be of interest, as described elsewhere in this chapter).

** Landfills included.

482. A number of more recent release inventories have been performed. Generally, they only include major sources of atmospheric releases – mainly from mercury impurities in high volume materials and to a lesser extent from the lifecycles of mercury in intentional uses. The totals from these studies are presented in table 6.10 along with the totals from table 6.9.

Table 6.10 Newer estimates of atmospheric releases from some major anthropogenic sources, as compared to totals from table 6.9 (metric tons/year).

Year	Atmosphere	Water	Soil	Reference
1983 Interval Mean	 900 - 6200+? 3560+?	 300 - 8800+? 4600+?	 2200 - 18000+? 10100+?	Nriagu and Pacyna, 1988 (see table above)
1990 ***1,3** Interval Best estimate	 1300 – 2100 1900	-	-	Pacyna and Pacyna, 1996
1992	2200	-	-	Pirrone *et al.,* 1996
1995 ***2,3**	1900	-	-	Pirrone *et al.*, 2001 - including Pacyna

Notes: +? means that real totals may be larger, as inputs given as "no estimate" are not included in presented totals.

1 Includes also 172 metric tons of mercury releases from chlor-alkali production and other smaller sources (Pirrone *et al.*, 2001).

2 Not including releases from gold extraction (has been estimated by Lacerda (1997) at up to 460 metric tons/year at about 1990, of which most was released to the atmosphere). Also not including releases from chlor-alkali production and "other sources". The authors of the inventory state that releases from waste incineration are most likely underestimated due to lack of national data on wastes (Pirrone *et al.*, 2001).

3 The uncertainty on the total is significant – the authors mention that an estimation accuracy of less than 50 percent can be assigned for mercury in Europe (Pirrone *et al.*, 2001). Most likely, the inaccuracy is higher for large parts of the world.

483. In table 6.11, the results of the global atmospheric emission inventory for 1995 are presented by source types included in the quantification, and geographical continents (as presented in Pirrone *et al.*, 2001). Here, the highest contribution within each source type has been put in bold text.

484. Pirrone *et al.* (2001) comment the trends in the geographic distribution of emissions as follows:

> "There have been major changes in emissions in 1995 compared to 1990, with respect to the location of major emission regions contributing the most to the global emission survey of the element. Whereas the mercury emissions in Europe and North America have decreased quite substantially during the period from 1990 through 1995, emissions in Asia, particularly in China and India, have increased significantly. The Asian sources contributed about 30 percent to the total emissions of mercury in 1990, compared to 56 percent in 1995. An increase of more than 250 metric tons was estimated for China between the years 1990 and 1995. The increase of mercury emissions in China from 1990 through 1995 is clearly related to the increase of coal combustion in the country. The mercury emission increase due to the increased combustion of coal has overcome a slight reduction of emission of air pollutants in the country due to the installation of high efficient emission control devices starting in the mid-1990's.
>
> Decrease of mercury emissions in Western Europe, the United States, and Canada can be explained by further installation of emission control equipment, particularly various flue gas desulfurisation

> (FGD) technologies, as already mentioned. Relatively low temperatures found in wet scrubber systems allow many of the more volatile trace elements to condense from the vapour phase and thus to be removed from the flue gases.
>
> Decrease of mercury emissions from combustion sources, as well as other industrial sources in Central and Eastern Europe from 1990 to 1995 was also caused by a general decrease of industrial activities and resulting decrease of the consumption of raw materials."

Table 6.11 Estimates of global atmospheric emissions of mercury from a number of major anthropogenic sources in 1995 (metric tons/year;Pirrone et al.*,1996; 2001).*

Continent	**Stationary combustion**	**Non-ferrous metal production**	**Pig iron and steel production**	**Cement production**	**Waste disposal *3**	**Total, quantified sources**
Europe	185.5	15.4	10.2	26.2	12.4	249.7
Africa	197.0	7.9	0.5	5.2		210.6
Asia	**860.4**	**87.4**	**12.1**	**81.8**	32.6	1074.3
North America	104.8	25.1	4.6	12.9	**66.1**	213.5
South America	26.9	25.4	1.4	5.5		59.2
Australia & Oceania	99.9	4.4	0.3	0.8	0.1	105.5
Total, quantified sources, 1995 ***4**	1474.5	165.6	29.1	132.4	111.2	1912.8
Total, quantified sources, 1990 ***1**	1295.1	394.4	28.4	114.5	139.0	2143.1 ***2**

Notes:

1 Estimates of maximum values, which are regarded as close to the best estimate value by the authors of the inventory. Totals represent total of the sources mentioned in this table, not all known sources.

2 The total emission estimate for 1990 also includes 171.7 metric tons from chlor-alkali production and other "less significant" sources.

3 Considered underestimated by authors of the inventory, see notes to table 6.9 above.

4 Does not include gold extraction, chlor-alkali production and "other sources", see notes to table 6.9 above.

485. For more information about emission control technologies and efficiencies, see section 8.3.

486. Geographical distribution of 1990 emissions to the atmosphere from major sources are visualised in figure 6.4 below. The designations in the figure are associated with uncertainties and not all source types are included. The figure gives, however, a good presentation of the global character of the mercury pollution problem.

6.3.7 Quantification of mercury releases

487. It should be kept in mind that almost any attempt to quantify anthropogenic releases to the environment would – in principle – tend to underestimate the total releases as compared to the true releases occurring. The reason is that whereas the contributions from actually quantified individual source types can – in principle – be both overestimated and underestimated, contributions from all relevant source types are very rarely quantified. Often, the collection of the data required for quantification of releases from less homogenous source types will demand larger resources.

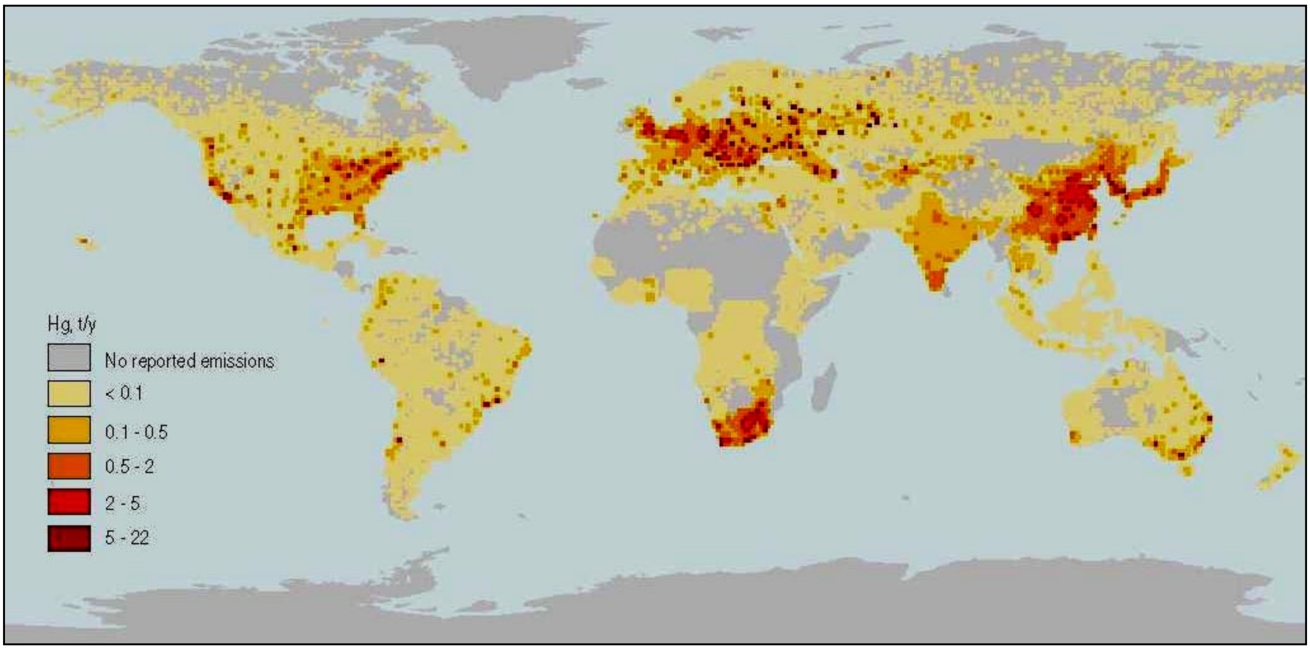

*Figure 6.4 Spatial distribution of global emissions of mercury to air within a 1*x1* grid. Source of data: J. Pacyna pers. comm., Canadian Global Emissions Interpretation Centre (CGEIC), as presented by AMAP (1998). Original figure presented courtesy of AMAP, Norway.*

488. Types of releases, which are often not included in aggregated inventories or are included with higher uncertainties, are:

- Releases to water, directly from industry and from public wastewater systems;
- Diffuse releases from uncollected waste containing products and materials with mercury content;
- Diffuse releases from informally incinerated waste;
- Diffuse releases from informal, unprotected waste dumps;
- Evaporation of mercury from controlled landfills and informal waste dumps;
- Releases (to air water and soil) from smaller industrial point sources;
- Releases from small-scale/artisanal gold extraction activities;
- Releases from end-of-pipe technology derived wastes.

489. A mass balance approach like national substance flow analyses (“SFAs” as for example described by Hansen and Lassen, 2000), where release estimates are evaluated versus the inputs to the economy, may be among the methods that give a more complete description of releases and paths of substances like mercury in society, provided a set of basic data are available or can be produced.

490. National and regional inventories of atmospheric emissions exist for European countries, USA, Canada and possibly a few other countries (see overview of European countries in Pirrone *et al*., 2001, chapter 2). A number of governmental and intergovernmental submissions to UNEP present data on estimated national and regional atmospheric emissions. The data may possibly add to the understanding of the anthropogenic release patterns as part of a more detailed study. This has, however, not been possible within the time period and the resources available at this stage of UNEP’s mercury assessment process.

6.4 Pathways of mercury to – and in – the environment

491. The aim of this section is to give an overview of the ways mercury mobilised by humans is released to the environment and how it is distributed, re-distributed and stored in and between environmental compartments. The further pathways leading to adverse effects on humans and the environment are described in chapters 4 and 5 respectively.

6.4.1 Mercury is persistent in the environment

492. A fact that is basic for the understanding of mercury's pathways in society and the environment is that it is an element and therefore cannot be broken down or degraded to harmless substances. As described, mercury may change between different states and species in its cycle, but its simplest form is elemental mercury, which itself is harmful to humans and the environment. This means that once mercury has been brought into circulation in the biosphere by human activity it does not "disappear" again in time spans comparable to human lifetime.

6.4.2 Fate of mercury introduced into society through intentional uses

493. In spite of strongly reduced use of mercury in some regions of the world, global mercury consumption for intentional uses in products and processes is still significant. Releases to the environment from these uses appear generally to be underestimated, most likely due to the complexity and higher research resources needed for such efforts.

494. Much of the mercury brought into use through products and for consumer purposes will end up in landfills with collected waste, or be lost, dumped or incinerated diffusely and informally directly in the environment. A significant part is expected to end up in the environment rather directly and quickly. How much this amounts to on a global level is difficult to estimate, though it may be possible to form rough estimates given sufficient resources. As indicated below, also the mercury used, collected and treated under more controlled conditions, may partly be spread to the environment over a longer range of time.

495. In some parts of the world waste collection is informal, inefficient or non-existing. In such cases, mercury in waste will be spread diffusely in the environment, incinerated under informal conditions, or disposed of in informal dumps with no protection against local soil and groundwater contamination.

496. In parts of the world with more regulated waste collection and disposal, landfills are often controlled and equipped with membranes for collection of water passing through the stored waste ("leachate") and facilities for the cleaning of the same leachate. After operation time, the waste is often covered with soil and vegetation. In these cases most of the mercury will normally be retained in the stored waste for decades or centuries, as the amounts leaching out with water and evaporating to the atmosphere is generally believed to be minimal in the initial phases of the landfills existence (for vapourisation, see below). On the other hand, leaching and evaporation of mercury will continue for decades, maybe centuries, and will require continued treatment of the leaching water. If this treatment is done in the general wastewater treatment system (normal procedure) most of the leaching mercury will end up in sewage sludge, which is sometimes spread as a fertiliser on farmland, and thus will add to the mercury release to the environment. Or the mercury content will prevent this utilisation of the sludge and therefore it will be incinerated, deposited or treated in some other manner. In the long term (centuries, millenniums), the fate of mercury in normal surface landfills cannot be considered well defined. Can we expect the cleaning of the leachate to continue for centuries? Will former landfills situated near urban areas become attractive for construction and housing activities and thus be exposed by excavation activities (a quite common situation already)? When will, ultimately, geological or climatic processes disturb the sealing of the landfill and potentially spread the deposited mercury over large areas (for Northern conditions, for example, this is likely to happen (ice age), the question is when)?

497. Some countries rely on controlled waste incineration, which reduce the waste volume and make use of the energy bound in the waste materials. Because of its low boiling point, most of the mercury is thermally released during the combustion, and will be emitted directly to the atmosphere, unless the exhaust gas is filtered effectively. In some industrialised countries filter facilities on waste incinerators have been improved during the last decade or two, and this is also reflected in decreased emissions of mercury (AMAP, 2000). Generally, only about 35-85 percent of the mercury is retained by filtering (Pirrone *et al.*, 2001), and parts of the mercury will still be emitted directly to the environment. However, carbon injection followed by filtration can increase the retention rate significantly. Mercury reten-

tion close to 100 percent is not normal (see section 8.3). The mercury eliminated from the exhaust gas is retained in incineration residues and, for some types of filtering technology, in solid residues from wastewater treatment (from scrubbing process). These residues are stored in landfills with the implications described above, or – depending of their content of pollutants – used for special construction purposes (under roads or similar). In some cases such solid residues are stored in special deposits for hazardous waste, which are additionally secured with top membranes eliminating or reducing evaporation and leachate production from the waste.

Overview of pathways of mercury from society to the environment

Destinations of releases to the environment and types of releases to each receiving environmental medium:

- **The atmosphere:** Local, regional and hemispherical/global transport with air masses and deposition, greatly dependent on speciation of the emitted mercury.
    - Emissions from major point sources and diffuse sources such as housing (fossil fuel combustion);
    - Emissions from cremation, primarily due to dental fillings containing mercury;
    - Diffuse releases from uncollected waste products (fluorescent lamps, batteries, thermometers, mercury switches, lost teeth with amalgam fillings etc.);
    - Evaporation of previous discharges to soil and water;
    - Evaporation of mercury disposed of on landfills;
    - Re-emission of mercury deposited from atmosphere.
- **Water – aquatic environment:** Marine (oceans), freshwaters (rivers, lakes etc.).
    - Direct discharges from industry and households to water receptors;
    - Indirect discharges via waste water treatment systems;
    - Deposition of mercury previously emitted to the atmosphere;
    - Surface run-off and leachate from mercury contaminated soil and landfills without leachate collecting membrane and leachate water cleaning system;
    - Wash-out of mercury previously deposited on soil.
- **Soil – terrestrial environment:** General soil surfaces and ground water, as well as concentrated storage in landfills (controlled or informal).
    - Disposal on landfills – with or without protection of groundwater and surrounding soil (membranes and leachate water cleaning system);
    - Diffuse releases from uncollected waste products (batteries, thermometers, mercury switches, lost teeth with amalgam fillings etc.);
    - Local releases from industry: On site materials and waste storage, broken/unused pipes, equipment and building material;
    - Spreading of sewage sludge with trace contaminants on agricultural land (used as fertiliser);
    - Use of solid residues from waste incineration and coal combustion for construction purposes (slag/bottom ash and fly ash);
    - Burial of persons with dental amalgam fillings;
    - Deposition of mercury previously emitted to the atmosphere.

498. As mentioned, many countries additionally make an effort to separate products with high mercury contents from the general waste stream. It has, however, proved difficult to reach high collection rates, particularly when the separation is to be done by the consumers. A high degree of information and motivation is necessary for successful separation by consumers, and the simplest possible separation system meeting the requirements, should be preferred. Irrespective of collection set-up, separate collection and treatment implies significant extra costs for the society.

499. Also, mercury is known to evaporate from landfills. For example, Canada has reported that in Ontario atmospheric mercury concentrations over three landfills were measured at 360-4,470 ng/m^3 compared to ambient mercury concentrations of 1.5-2.0 ng/m^3 across Canada (Pilgrim, 1998). On the other hand, a more recent survey by Environment Canada indicated a mercury concentration of approximately 10 ng/m^3 in landfill gas (Canadian submission, sub42gov). Meanwhile, recent studies (Lindbergh *et al*., 2001, among others quoted by the USA, Comm-24-gov) indicate that mercury emis-

sions from landfills may be higher than previously estimated. It is clear that as long as a fuller understanding of the significance of this mercury release pathway on a global scale has not been reached, it should be a focus of ongoing research.

500. Lindbergh *et al*. (2001) has also found methylmercury being emitted from investigated municipal waste landfills. Based on the knowledge of chemical transformation processes in landfills, transformation of mercury to the more toxic methylmercury (or dimethylmercury) could likely be a general phenomenon in municipal waste landfills. This pathway bypasses the bio-transformation in the aquatic environments and - of particular concern if landfill emissions are significant – adds directly to the methylmercury load and related impacts on humans and the environment.

6.4.3 Fate of mobilised mercury impurities in high volume materials

501. Significant parts of the mercury mobilised by humans through the use of materials with low natural contents of mercury impurities are released diffusely into the environment with no ways of retaining the mercury. A significant example is the use of coal and other fossil fuels in households and many industrial boilers.

502. In the increasing industrial activity of the world, large volumes of materials (coal, metal and ore, lime, plastics, some high volume chemicals, etc.) are used, which contain small traces of mercury impurities. As mentioned in other sections of this chapter, these sources constitute major parts of both national and global releases of mercury to the environment.

503. In some parts of the world, major point sources of releases of mercury from impurities in high volume materials are equipped with emission reduction technology, which reduces the direct outlets of mercury, as well as other pollutants, to the environment. As mentioned in section 6.3.6, the use of such measures have been increasing in Europe and North America during the last decade or two, and implementation has also begun in latter years in other regions, such as East Asia.

504. Descriptions of the capacity of such measures to retain mercury from direct releases to the environment are given in chapter 8. Mercury retained in solid residues from emission reduction technology is generally stored in landfills implying intermediate protection and potential long-term releases as described for intentional mercury uses above. Liquid (water) residues from certain emission reduction technologies are generally treated in waste water cleaning plants integrated in the facility, or in the public waste water treatment system, with the implications mentioned for landfill effluents above.

6.4.4 The global mercury cycle

505. It is important to understand that the origins of atmospheric mercury deposition (flow of mercury from air to land and oceans) are local as well as hemispherical or global. Several large studies have supported the understanding that besides local sources, like industry, coal combustion and waste incineration, also the general background concentrations in the global/hemispherical air contributes significantly to the mercury burden at any location (see for example US EPA, 1997; Munthe *et al.*, 2001; Pirrone *et al*., 2001). Similarly, virtually any local source contributes to the background levels – the global mercury pool in the biosphere. Also the ocean currents are media for long-range mercury transport, and the oceans are important dynamic sinks of mercury in the global cycle.

Movements of mercury in and between environmental compartments

506. As mentioned, mercury is a natural element that cannot be created or destroyed and the same amount has existed on the planet since the earth was formed. A significant amount of research indicates that natural and human (anthropogenic) activities can redistribute this element in the atmospheric, soil and water ecosystems through a complex combination of transport and transformations. Figure 6.5 below illustrates the main interactions between the environmental compartments.

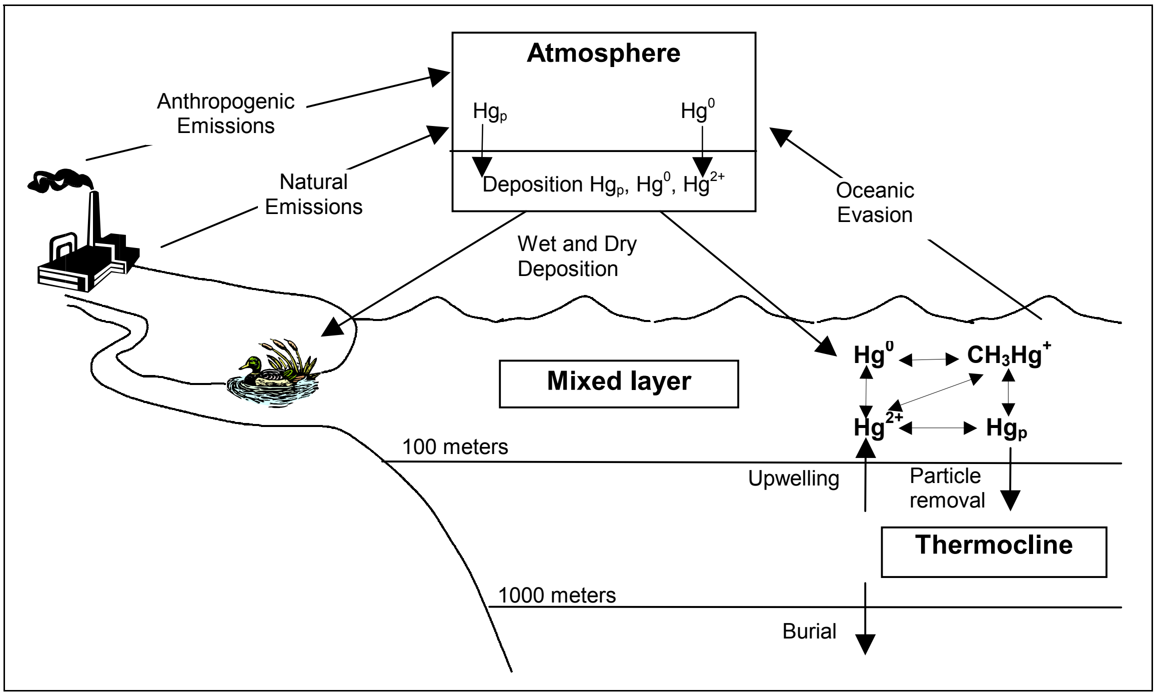

Figure 6.5 Dynamic interactions of mercury distribution between the environmental compartments (based on Lamborg et al.*, 2002, as adapted from Mason* et al.*, 1994).*

Air

507. Mercury is emitted to the atmosphere from a variety of point and diffuse sources and is dispersed and transported in the air, deposited to the earth and stored in or redistributed between water, soil and atmospheric compartments. Therefore, mercury cycling and mercury partitioning between different environmental compartments are complex phenomena that depend on numerous environmental parameters. Wet deposition was, until recently, assumed to represent the primary mechanism for transfer of mercury and its compounds from the atmosphere to aquatic and terrestrial receptors. However, studies by US EPA, the Florida Department of Environmental Protection and US Department of Energy have all shown that dry deposition of divalent gaseous mercury species can be equal or greater than wet deposition, even in moist climatic areas such as the Florida Everglades and the Great Lakes Region with relatively high annual precipitation (Rea *et al.,* 2000; 2001; Vette *et al.,* 2002; Landis *et al.,* 2002). The chemical and physical form of mercury in air affects the mechanisms by which it is transferred to the earth surface and ultimately influences the total depositional flux. An increase in ambient air concentrations of mercury will result in an increase of direct human exposure and an increase of mercury flux entering terrestrial and aquatic ecosystems leading to elevated concentrations of methylmercury in freshwater and marine biota. Extensive research conducted on mercury deposition in Boreal forests systems has shown that the main source of mercury and methylmercury to the forest floor is litterfall, i.e. needles, branches (Iverfeldt, 1991; Munthe *et al.,* 1995). This mercury and methylmercury mainly originates from the atmosphere (not via root uptake) and adsorbs on plants surfaces via dry deposition.

508. Monitoring networks for wet deposition of mercury have been established in North America and in Europe for the purposes of providing an indication of the magnitude of depositional flux and to provide data for evaluation and testing of atmospheric mercury simulation models. Figure 6.6 shows the monitoring stations established for North America within the Mercury Deposition Network as of 2001 with observations of accumulated wet deposition of mercury and average mercury concentration in precipitation for that year. Figure 6.7 shows similar results from the wet deposition network established in Sweden. The Swedish stations are a part of the EMEP monitoring activity under the UNECE LRTAP Convention. Similar networks for monitoring dry deposition of mercury are needed to provide a complete measure of depositional flux and to provide data for simulation model testing and evaluation.

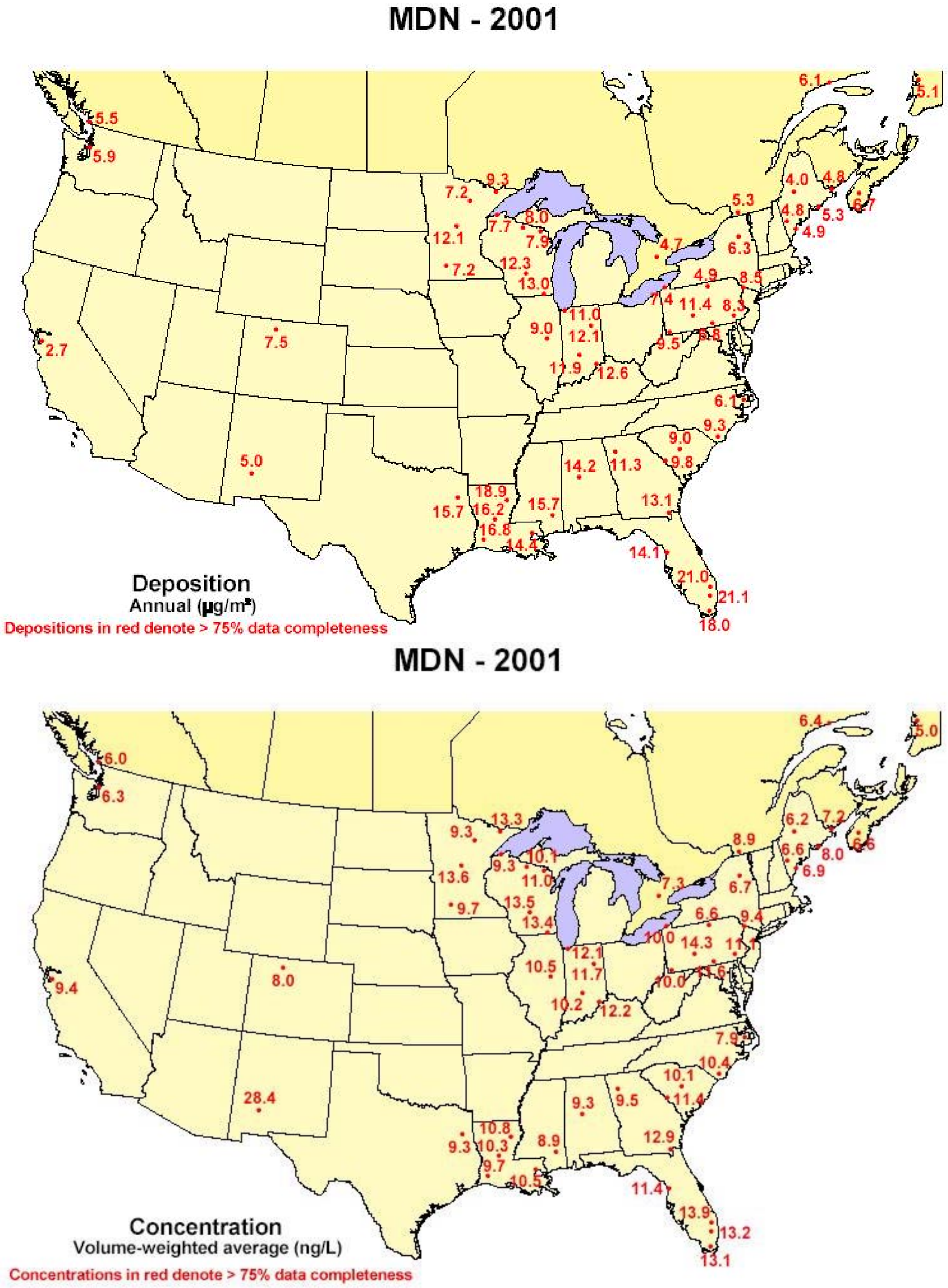

Figure 6.6 Monitoring stations established for North America within the Mercury Deposition Network as of 2001 with observations of accumulated wet deposition of mercury and average mercury concentration in precipitation for that year. Figures are from the MDN web page: http://nadp.sws.uiuc.edu/mdn/.

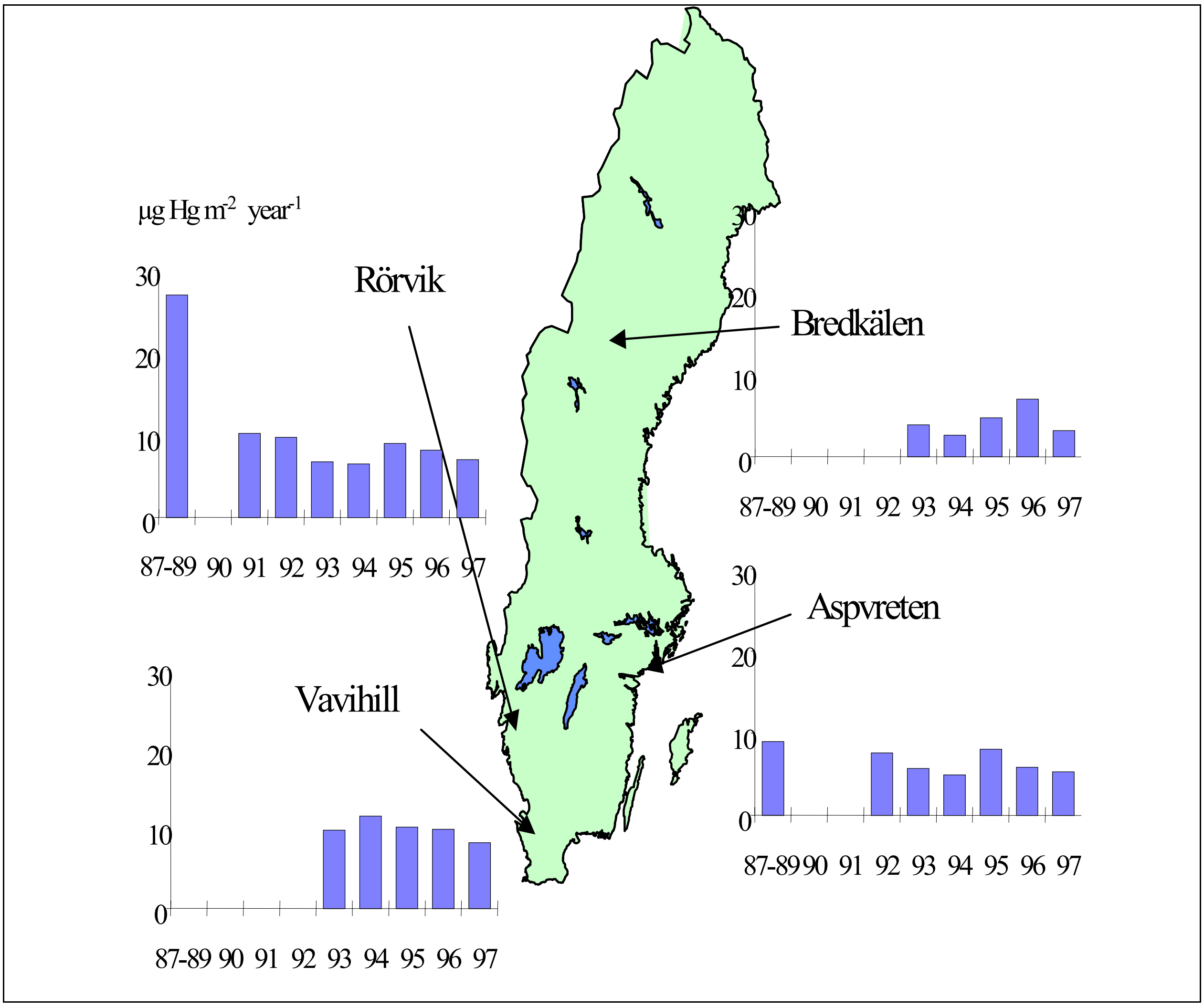

Figure 6.7 *Monitoring stations and results (wet deposition measured in years noted) from the wet deposition network established in Sweden. The Swedish stations are part of the EMEP monitoring activity under the UNECE LRTAP Convention. Figure provided by John Munthe, IVL, Sweden.*

509. A recent evaluation of mercury levels in 1 kg pike in Swedish lakes has revealed a decrease when comparing concentrations found between the periods 1981-1987, and those measured in 1988-1995. The decrease may be attributed to documented decreases in atmospheric deposition during this period (Johansson *et al.*, 2001). Similar effects appear to be occurring in the Florida Everglades in the USA following the implementation of mercury emission controls on waste incinerators in the Miami area, but these results are preliminary and have not been published in the peer-reviewed scientific literature.

Water

510. Once in aquatic ecosystems, mercury can exist in dissolved and/or particulate forms and can undergo chemical/microbial transformation to methylmercury as described in section 2.3. Contaminated sediments at the bottom of surface waters can serve as an important mercury reservoir, with sediment-bound mercury recycling back into the aquatic ecosystem for decades or longer.

Soil

511. Mercury has a long retention time in soil and as a result, the mercury accumulated in soil may continue to be released to surface waters and other media for long periods of time, possibly hundreds of years.

Environmental long-range transport

512. Mercury pollution is transported over long distances by air as well as water movements. In particular, air transport is believed to be important for mercury, as mercury in the form of vapourised elemental mercury may be transported quickly over long distances and thus air transport may be responsible for the distribution of mercury to the most remote parts of the Earth. For example, the AMAP-assessment (AMAP, 1998) points at mining and metallurgical sources in the Northern part of Russia, besides industrial regions in Europe and North America, as the dominating sources of other heavy metals in the air in the High Arctic during winter time. Contrary to other heavy metals, the large volume of atmospheric mercury emissions is emitted as the element in a gaseous state. Mercury vapour is capable of being transported over long distances with the air masses. Newer evidence suggests that the background levels of mercury in the atmosphere (from anthropogenic and natural sources) contribute significantly to the mercury burden in remote areas like the Arctic. The remaining part of mercury air emissions are in the states of ionic or gaseous mercury compounds/ions, which are deposited by both dry and wet atmospheric processes close to the source, mainly within a radius of a few hundred kilometres.

513. A group of scientists, including several of the world's top specialists on atmospheric mercury research, conclude the following in a recent review of the environmental impact of mercury in Europe (Pirrone *et al*., 2001):

> "Long-range transport of mercury in Europe was first observed in the late seventies in Sweden (Brosset, 1982). Since then long-term monitoring activities carried out in Scandinavia have shown a clear gradient in wet deposition of mercury with elevated fluxes in the south-western part of the region, i.e. closer to the main emission sources in Central Europe (Iverfeldt, 1991; Munthe *et al*., 2001a). Similar patterns have been shown in North America. The Scandinavian studies have also revealed a significant decrease in wet deposition after a reduction of mercury emissions around 1990 (Iverfeldt *et al*., 1995; Munthe *et al*., 2001a).

514. Recent research projects conducted within the Environment and Climate Research Programme have revealed that the anthropogenic influence on atmospheric mercury levels in Europe are still considerable despite reductions in emissions during the last decade (Pirrone *et al*., 2000; Munthe *et al*., 2001). These research projects have also clearly shown the influence of the hemispherical/global cycling of mercury. The authors conclude that, despite the significant decreases in mercury emissions during the last decade, the atmospheric deposition is still significantly increased in comparison to pre-industrial times. They state that, according to their judgement, further reductions are needed to protect sensitive ecosystems and to prevent and decrease levels of methylmercury in freshwater fish in Scandinavia and elsewhere. A significant influence from background contributions was also noted. The authors assume that a large portion of the mercury present in the global atmosphere today is a result of decades of emissions from anthropogenic activities. They state that the natural component of the total atmospheric burden is difficult to estimate, but is probably on the order of 20 to 40 percent and that anthropogenic activities have thus increased the levels of mercury in background air by roughly a factor of 3.

515. A similar understanding is expressed by the US EPA (1997) in their "Mercury report to Congress".

"The polar sunrise mercury depletion incidence"

516. A special phenomenon has been shown to influence the deposition of mercury in the Polar regions. It has been termed "the polar sunrise mercury depletion incidence" or "the mercury sunrise", as a highly elevated deposition of mercury is taking place during the first few months of the Polar sunrise (best studied in the Arctic). It appears that the solar activity and present ice crystals influence the atmospheric transformation of elemental gaseous mercury to divalent mercury, which is more rapidly deposited. The mercury depletion happens at the same time as the surface-level ozone depletion (a separate phenomenon from the better known ozone depletion in the stratosphere).

517. This polar phenomenon poses a special challenge to atmospheric mercury transport modellers, because they need to understand the mechanism of the phenomenon to predict mercury exchange and deposition in and around the Polar regions.

518. The net atmospheric input to Polar ecosystems resulting from this phenomena is not known in detail. Re-emissions of mercury occur from the snow surface and during snowmelt, but the depletion events may still result in significant input to the aquatic environment. In case this phenomenon shows up to be resulting in higher yearly mercury deposition rates in the Polar regions than in other regions of the world, this could mean that the Polar regions serve as "mercury cold traps" collecting an un-proportionally high part of the global mercury emissions. This would fit well with the observed high mercury concentrations in the Arctic aquatic environment.

519. Mercury depletion has now been observed in Alert, Canada (Schroeder *et al.*, 1998; Lu *et al.*, 2001), in Barrow, Alaska, USA (Lindberg *et al.*, 2002b), Svalbard (Berg *et al.*, 2002), in Greenland (Skov, 2002) as well as in the Antarctic (Ebinghaus *et al.*, 2002), and can thus be described as a generally occurring polar phenomena which may influence the total input to Polar ecosystems.

520. Suggestions for other references for further reading about the polar mercury depletion incidence are Schroeder *et al.* (1998) and Lu *et al.* (2001).

Accumulated anthropogenic mercury burden

521. Mercury from natural sources is present in the environment, but the anthropogenic contribution to the environmental mercury burden is evident. On average around the globe, there are indications that anthropogenic emissions of mercury have since pre-industrial times resulted in 50-300 percent increases in deposition rates, and in and around industrial areas the deposition rates have increased by a factor of 2-10 during the last 200 years (Bergan *et al.,* 1999; Lindquist *et al.,* 1984; as cited in von Rein and Hylander, 2000). Such information can be derived from mercury concentration profiles in lake and ocean sediments and peat bogs, and from geographical trends in soil mercury concentrations, among others.

522. Profiles of mercury concentrations in different depths from the sediment surface give a picture of the changes in the mercury burden over time. Several natural conditions, such as local currents, oxygen concentrations and biological activity, influence the immobilisation and re-mobilisation of mercury bound in sediments. Therefore, the locality from which mercury profiles are taken for this purpose should be selected with care, and the result should be interpreted cautiously, particularly for the most recent upper layers, which may still be affected by re-mobilisation (HELCOM, 2001).

523. However, in a very recent paper Schuster *et al.* (2002) used a glacial ice-core record to study atmospheric mercury deposition during the last 270 years. Among other observations, they concluded that the anthropogenic contribution during the last 100 years rose to 70 percent of the total. On the other hand, declines in atmospheric mercury deposition were apparent in both the ice-core record and in sediment-core records over the last ten years (Schuster *et al.*, 2002, as cited by the World Chlorine Council: Comm-4-ngo). While keeping in mind the caveat above, this may suggest that the major anthropogenic influence on atmospheric mercury deposition during the industrial era is now beginning to decline.

524. As an example of indications of the accumulated mercury burden over time in different geographical regions, mercury concentrations in marine sediments from the Arctic, Skagerrak in the greater North Sea area (OSPAR waters of North Europe), and the Baltic (HELCOM waters), are presented in the figures 6.8-6.11 (the selection of illustrations is somewhat arbitrary – many examples exist in the literature). It is notable that most profiles show the same trend of increased mercury concentrations in industrial times.

525. For the Arctic (figure 6.8), it is concluded in the AMAP assessment (1998) that several data sets indicate widespread accumulation of mercury in surficial Arctic sediments. The enrichments occur particularly in the upper 2-10 cm of the sediments, even at the North Pole. The report states that this phenomenon could indicate global scale input to the marine environment in recent times, but that more investigations are required, before definite conclusions could be drawn about the source of the observed enrichment.

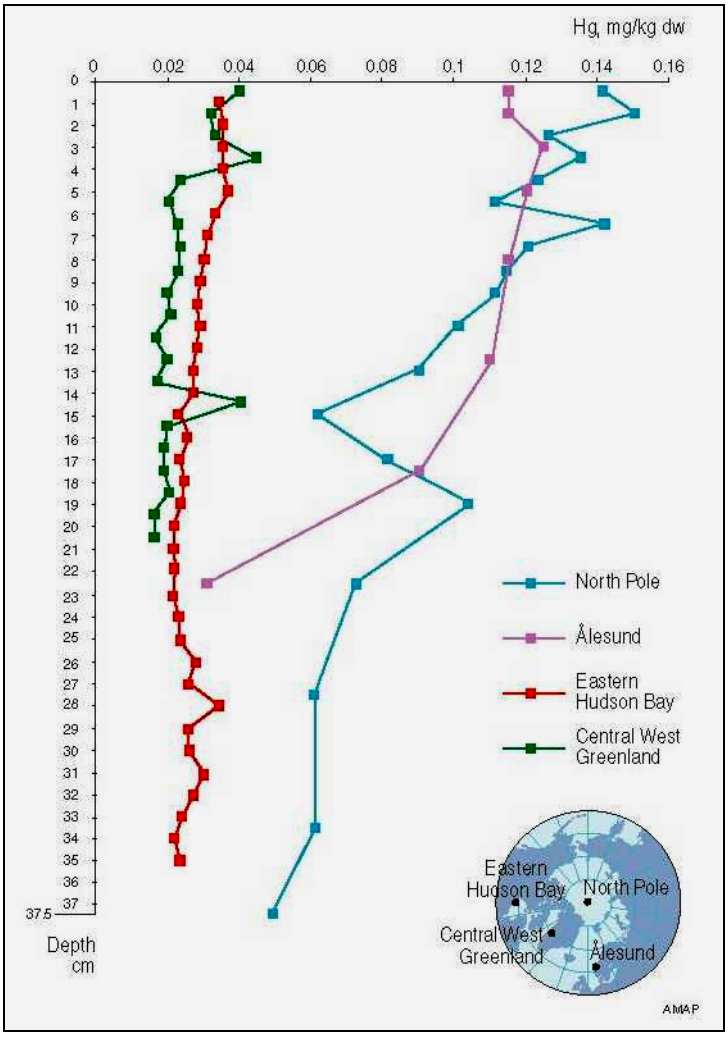

Figure 6.8 Examples of mercury concentrations in sediment profiles from the Arctic marine area (AMAP, 1998).[7] Original figure presented courtesy of AMAP, Norway.

526. The profiles from Skagerrak (figure 6.9) and the Baltic area (figures 6.10 and 6.11) have been dated. Here, mercury concentrations have risen during the last century. For the Baltic profiles there is an indication that the mercury burden has decreased during the last few decades. This appears reasonable, as control of regional releases has been strengthened considerably in Scandinavia in this period (Submission from the Nordic Council of Ministers, sub84gov). The overall pattern in the European waters is that the mercury concentrations in marine sediments are highest close to shores and river outlets with high anthropogenic activity and industrial sources (like pulp and paper industry and chlor-alkali industry) (OSPAR, 2000; HELCOM, 2001).

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[7] Possible reasons for the somewhat deviating mercury enrichment pattern for Hudson Bay are not described in the reference - a different age scale of the local profile could appear to be one possible explanation.

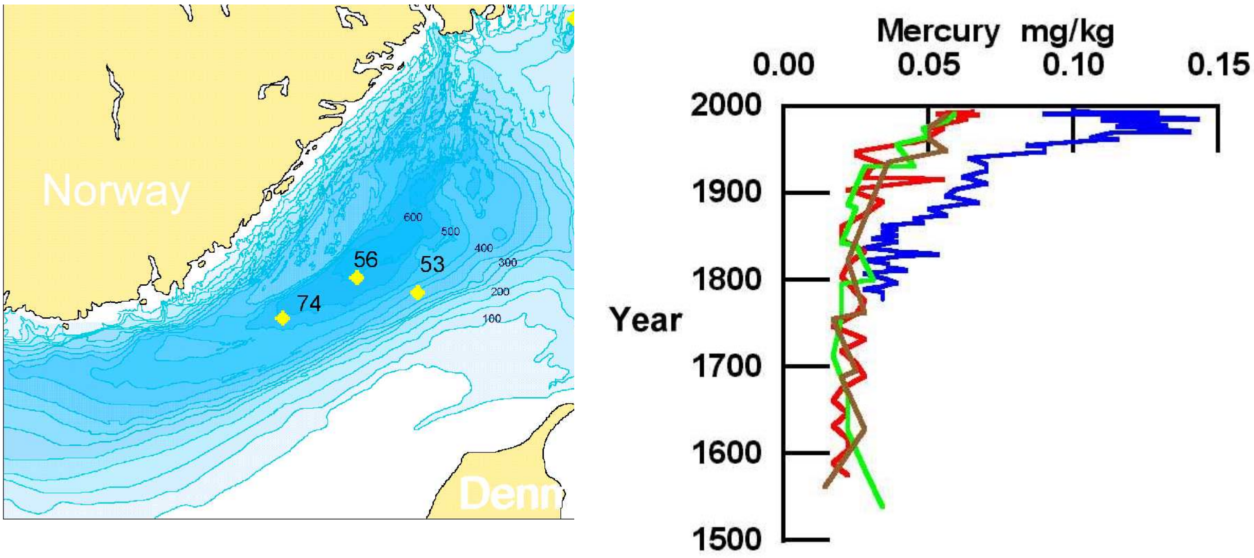


Figure 6.9 *Examples of mercury in sediment profiles from Skagerrak south of Norway in the OSPAR Convention marine area (Oddvar and Thorsnes, 1997). Blue line: Profile from station 2 nearest the Oslo Fjord and the Swedish coast. Original figures presented courtesy of Geological Survey of Norway (NGO).*

527. A number of researchers have questioned under what conditions sediment profiles in remote areas without local pollution can be taken as evidence for an elevated global or hemispherical atmospheric background mercury concentration, as otherwise commonly agreed among scientist in this field. The question is whether mercury is mobile enough to change physical position in the upper sediment layers during early geo-chemical changes, so-called “diagenesis”.

528. The question has been the subject of some discussion in recent literature. For example, Fitzgerald *et al*. (1998) has “examined the weaknesses in interpretation and the choice of information that has been used to argue against atmospheric mercury contamination” and reviews several sets of data from other investigations, which cannot – from their judgement – be explained by diagenesis. Among other arguments, Fitzgerald *et al*. (1998) claim the older ice core studies from Greenland, used for argumentation by the critics, were not using the ultra-clean sampling techniques known today, and produced results contaminated by the sampling equipment. Newer studies from the Greenland ice cap support the conclusions of a general increase of atmospheric background levels due to anthropogenic emissions. Fitzgerald *et al*. (1998) conclude that despite uncertainties in current understanding, there is a broad and geologically consistent data base indicating that, over large regions of the globe, anthropogenic mercury emissions have increased relative to natural sources since the onset of the industrial period.

529. Investigations of mercury concentrations in lake sediment profiles performed in the 1980’s in Sweden clearly show an increase in mercury concentrations in surface sediments (Johansson, 1985). The increase is large in sediment profiles taken in the southern part of the country whereas lake sediments from lakes in the north show very little increase. This clearly indicates the influence of long-range transport from source areas on the European continent. In more recent lake cores from Southwestern Sweden, mercury concentrations in surficial sediments decrease corresponding to a reduced atmospheric input in the 1990’s (Munthe *et al.*, 1995).

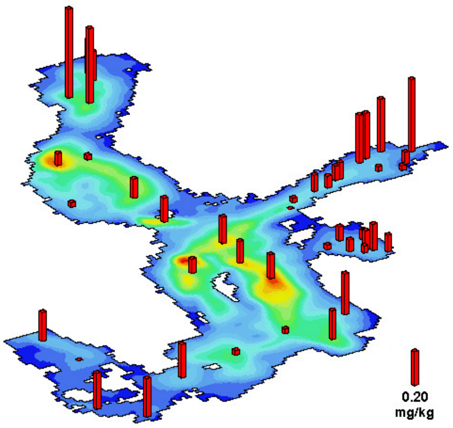


Figure 6.10 *Mercury levels in surface sediment in the Baltic Marine Area (mg//kg dw; salt-corrected values). The yellow and orange areas indicate the deep basins. Orientation: Denmark is situated in the lower left corner of the figure - Russia in the higher right corner. Figure from HELCOM (2001), original presented courtesy of HELCOM, Finland.*

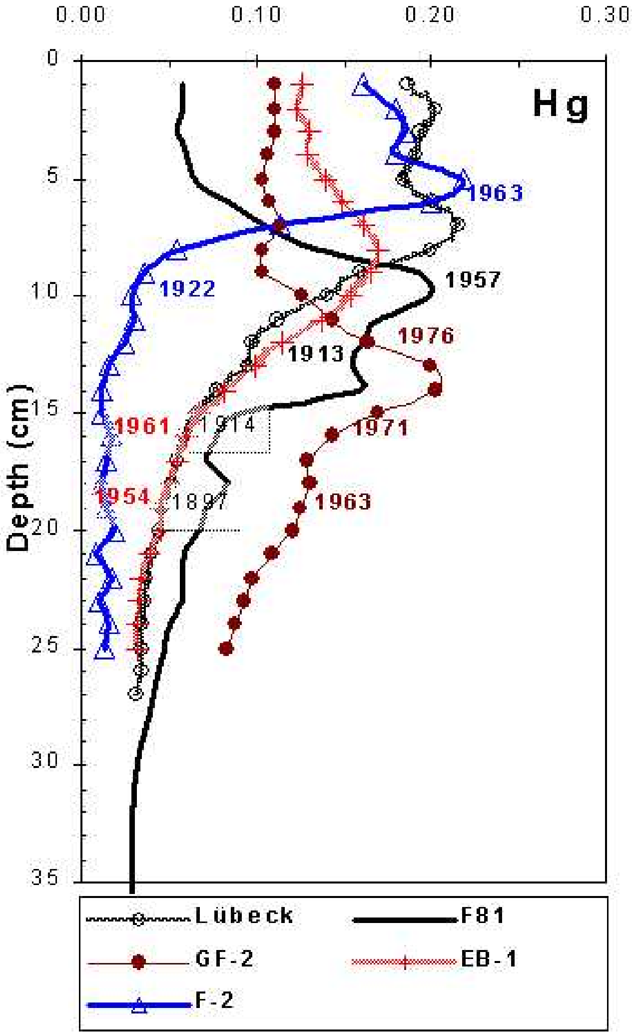


Figure 6.11 *Vertical distribution of mercury (mg/kg dry-weight basis) in sediment from Lübeck Bay, Gdansk Bay, Gulf of Finland (GF-2), Bothnian Bay (F-2) and Bothnian Sea (EB-1) in 1993. The age of the sediment is indicated. Figure from HELCOM (2001), original presented courtesy of HELCOM, Finland.*

6.4.5 Atmospheric transport models for mercury

530. For a couple of decades efforts have been invested in developing models able to describe the often complex picture of atmospheric cycling of mercury in different regions of the world. Today models exist for parts of the Northern Hemisphere allowing scientist to describe air transport of substances like mercury and predict mercury deposition rates as related to geographical position, as well as monitoring the consequences of changes in emission patterns. Simulation modeling plays a critical role in developing a better understanding of atmospheric mercury cycling when combined with basic observational study. When model results are compared to observations, the incidents of poor agreement are used to isolate important scientific uncertainties which can be addressed by further basic research. The

models are then updated to reflect any new atmospheric source or process information obtained and tested against observations once again. This iterative cycle of modelling and basic research continues until the desired model accuracy with respect to observation is demonstrated. At this time, there remain serious discrepancies between model simulations and observed atmospheric mercury concentrations and deposition fluxes, and model inter-comparison studies have shown differing results from various models when simulating identical circumstances (see Ryaboshapko *et al.*, 2001). This suggests that our scientific understanding of atmospheric mercury remains flawed, incomplete, or a combination of both.

531. Atmospheric models of mercury transport have been developed for the last decade both on regional and global/hemispheric scales. Regional models cover North America (Bullock *et al.*, 1997; Pai *et al.*, 1997; Seigneur *et al.*, 2001; Bullock and Brehme, 2002) and Europe, including European part of Russia (Petersen *et al.*, 2001; Ilyin *et al.*, 2001). Global or hemispheric models could be divided into box-type ones describing general cycling of mercury in the environment by means of large reservoirs (Mason *et al.*, 1994; Lamborg *et al.*, 2002) and grid models calculating long-range mercury transport and deposition over the globe (Bergan *et al.*, 1999; Seigneur *et al.*, 2001; Travnikov and Ryaboshapko, 2002). Comparison and evaluation of different mercury transport models are performed within the mentioned models intercomparison campaign (Ryaboshapko *et al.*, 2001). Creation of global models has also been attempted, based on mass balance (Mason *et a*l., 1994) or meteorological transport (Bergan *et a*l., 1999 and Shia *et a*l., 1999) approaches.

532. An impression of the development and state of the art of mercury transport modelling can be obtained in the following documents:

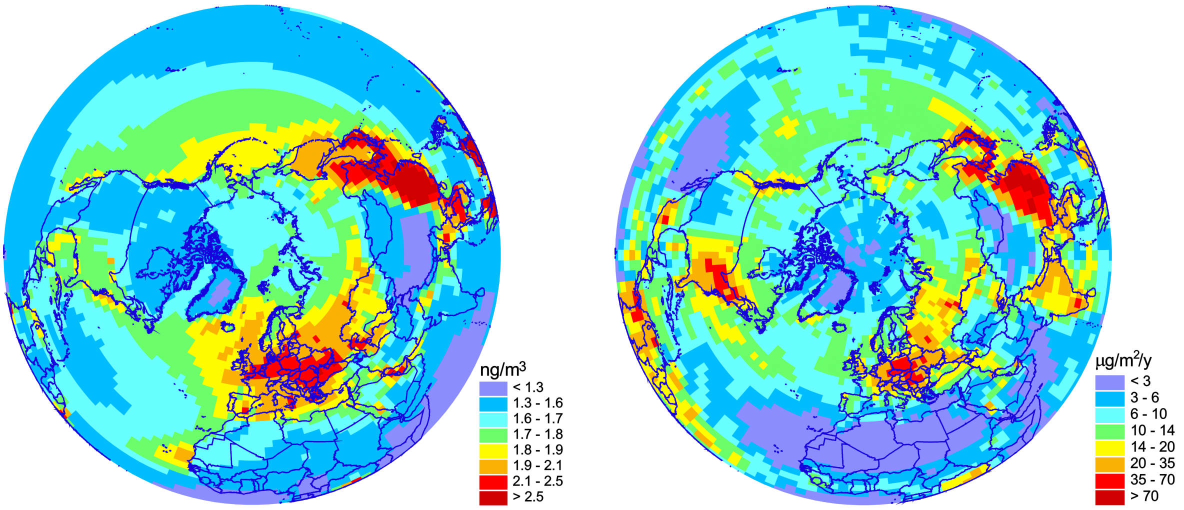
- 1996: Global and regional mercury cycles: Sources, fluxes and mass balances (Baeyens *et al.*, 1996).
- 1999: Proceedings from the WMO/EMEP/UNEP workshop on modelling of atmospheric transport and deposition of persistent organic pollutants and heavy metals (WMO/EMEP/UNEP, 2000).
- 2000: Current methods and research strategies for modelling atmospheric mercury (Bullock, 2000); which gives a description of current methods and research strategies for modelling atmospheric mercury transport, transformation and deposition in North America and Europe.
- 2001: Summary and findings from the AMAP-NMR-MEPOP International Workshop on Mercury and POPs, held in Roskilde, Denmark, 10-12 September 2001 (Annex 3 of the submission from the Nordic Council of Ministers, sub84gov).
- 2001: EU Ambient Air Pollution by Mercury (Hg) – Position Paper (Pirrone *et al.*, 2001); which gives a good description of atmospheric mercury transport and deposition modelling as well as the most recent results from Northern Europe and the Mediterranean area.
- 2002: Comparison of mercury chemistry models (Ryaboshapko *et al.,* 2002); which describes a comparison of the model treatments for mercury in cloud/fog water in various long-range transport models under development in North America and Europe.

533. Quite a number of documents on mercury transport modelling and its results have been produced in connection with the EMEP programme and other activities relating to the LRTAP Convention performed under the auspices of UN ECE, see the submissions from UN ECE (attachments to sub9igo).

534. Annual operational calculations of mercury transboundary transport and depositions within the European region are performed by Meteorological Synthesizing Centre East of EMEP (MSC-E). Mercury concentration levels in the ambient air and deposition fields for each Party of the LRTAP Convention are assessed along with mutual mercury transport between countries. Besides, recently developed within the joint project of EMEP and AMAP, a hemispheric model allows for the evaluation of mercury contamination in the Northern Hemisphere. Results of the hemispheric mercury transport modelling are presented in Figure 6.12 (Travnikov and Ryaboshapko, 2002). The modelling results show that gaseous mercury is more or less uniformly distributed in the Northern Hemisphere (note differences in scale), while deposition fluxes vary significantly (up to 2 orders of magnitude) from industrialized to remote

regions. It is possible to distinguish the three areas most contaminated by mercury: Southeastern Asia, Europe and the eastern part of North America.

535. Some national submissions to UNEP give information on ambient air concentrations, which might add further to the understanding of the atmospheric transport of mercury.



a) Mean annual concentration of total gaseous mercury

b) Total annual mercury deposition

Figure 6.12 *Mean annual concentration of total gaseous mercury (a) and total annual mercury deposition (b) in the Northern Hemisphere – note differences in scale. From* Travnikov and Ryaboshapko *(2002); submitted by MSC-E of EMEP (comm-4-igo).*

6.4.6 Watershed cycling models for mercury

536. As with modelling the atmospheric cycling of mercury, modelling efforts to address the watershed cycling of mercury have received increasing attention in the past two decades. The modelling is also complex, due to the numerous species and transformation processes possible, and the difficulty in quantifying each. One modelling effort that has been developed and applied in North America is the Mercury Cycling Model. The model, initially developed for lakes, considers mercury inputs to and losses from the water body, reaction processes (e.g. methylation and demethylation, reduction of dissolved reactive mercury to elemental mercury, etc.), fluxes between compartments (e.g. particle settling to sediments, sediment resuspension), and other components. The model, which has undergone various modifications, has been applied in several locations, including a temperate lake in northern Wisconsin and the Florida Everglades, as part of US EPA's pilot mercury Total Maximum Daily Load (TMDL) project. For information on the model see Hudson *et al.* (1994).

537. A simpler modelling approach has been utilized by US EPA in the development of mercury TMDLs in the south-eastern USA. The effort involved combining the water column fate and transport model WASP5 with a GIS-based watershed characterization system and a mercury loading spreadsheet. The model system requires site-specific mercury data for parameterization. The authors noted that although uncertainties in a number of processes remain to be reduced, limited application of the modelling system has produced results that agree reasonably well with ambient data (Ambrose and Wool, 2002).

7 Current production and use of mercury

7.1 Overview

Origin of mercury

538. Mercury is a natural component of the earth, with an average abundance of approximately 0.05 mg/kg in the Earth's crust, with significant local variations. Mercury ores that are mined generally contain about one percent mercury, although the strata mined in Spain typically contain up to 12-14 percent mercury. While about 25 principal mercury minerals are known, virtually the only deposits that have been harvested for the extraction of mercury are cinnabar. Mercury is also present at very low levels throughout the biosphere. Its absorption by plants may account for the presence of mercury within fossil fuels like coal, oil and gas, since these fuels are conventionally thought to be formed from geologic transformation of organic residues.

Sources of mercury to the market

539. The mercury available on the world market is supplied from a number of different sources, including (not listed in order of importance):

- Mine production of primary mercury (meaning extracted from ores within the earth's crust):
  - either as the main product of the mining activity,
  - or as by-product of mining or refining of other metals (such as zinc, gold, silver) or minerals;
- Recovered primary mercury from refining of natural gas (actually a by-product, when marketed, however, is not marketed in all countries);
- Reprocessing or secondary mining of historic mine tailings containing mercury;
- Recycled mercury recovered from spent products and waste from industrial production processes. Large amounts ("reservoirs") of mercury are "stored" in society within products still in use and "on the users' shelves";
- Mercury from government reserve stocks or inventories;
- Private stocks (such as mercury in use in chlor-alkali and other industries), some of which may later be returned to the market.

540. The mining and other mineral extraction of primary mercury constitute the human mobilisation of mercury for intentional use in products and processes. Recycled mercury and mercury from stocks can be regarded as an anthropogenic re-mobilisation of mercury previously extracted from the Earth.

Continued mining of primary mercury

541. Despite a decline in global mercury consumption (global demand is less than half of 1980 levels), supply from competing sources and low prices, production of mercury from mining is still occurring in a number of countries. Spain, China, Kyrgyzstan and Algeria have dominated this activity in recent years, and several of the mines are state-owned. Table 7.1 gives information on recorded global primary production of mercury since 1981. There are also reports of small-scale, artisanal mining of mercury in China, Russia (Siberia), Outer Mongolia, Peru, and Mexico. It is likely that this production serves robust local demand for mercury, often for artisanal mining of gold[8]. Such mercury production would require both accessible mercury ores and low-cost labor in order for it to occur despite low-priced mercury available in the global commodity market.

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[8] In some countries, such as China, the artisanal mining of mercury or gold – or both – are illegal, but the enforcement of such legislation varies depending on many local factors.

Table 7.1 Recorded global primary production of mercury since 1981, metric tons/year.

Period	**1981-1985**	**1986-1989**	**1990-1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Recorded annual, global primary production (in metric tons)	5500-7100	4900-6700	3300-6100	2600-2800	2500-2900	2000-2800	2100-2200	1800

Sources: See section 7.2.1.

Large supplies of recycled mercury may be marketed

542. Large quantities of mercury have come onto the market as a result of ongoing substitution and closing of mercury-based chlor-alkali production in Europe and other regions. Market analysis indicates that 700 - 900 metric tons per year of recycled mercury (corresponding to about 30 percent of the recorded primary production) has been marketed globally since the mid-1990's, of which the majority originated from chlor-alkali production facilities (see section 7.3.1). However, to the extent there remains a legitimate demand for mercury, the re-use and recycling of mercury replaces the mining and smelting of virgin mercury, which would involve additional releases and would result in mobilising new mercury into the market and the environment.

543. The preference for reuse and recycling of mercury over mining - especially in the context of large mercury inventories coming onto the market - is complicated by the generally accepted economic rule that an **excess** supply of mercury drives the market price lower, which in turn encourages additional use or waste of mercury. For this reason, certain precautions are being taken, as described below.

544. Within the current decade and beyond, vast supplies of mercury will become available from conversion or shutdown of chlor-alkali facilities using the mercury process, as many European countries[9] press for a phase-out of this process before 2010. From the European Union alone, this may introduce up to 13,000 metric tons of additional mercury to the market (equal to some 6-12 years of primary mercury production; see section 7.4.1 on chlor-alkali production). In response to this potential glut of mercury, Euro Chlor, which represents the European chlor-alkali industry, has signed a contractual agreement with Miñas de Almadén. The agreement provides that Miñas de Almadén in Spain will buy the surplus mercury from West-European chlor-alkali plants and put it on the market in place of mercury Almadén would otherwise have mined. All EU members of Euro Chlor have agreed to sell their surplus mercury to Almadén according to this agreement, and Euro Chlor believes most of the central and eastern European chlorine producers will also commit to this agreement. While this agreement clearly represents an effort by all parties to responsibly address the problem of surplus mercury, some people have the view that there are not yet adequate controls on where this mercury would be sold or how it would be used.

545. Similarly, large reserve stocks of mercury held by various governments have become superfluous, and are subject to future sales on the world market if approved by the relevant national authorities. This is the case in the USA, for example, which holds a 4,435 metric ton inventory of mercury. The sale of this mercury has been suspended since 1994, awaiting a determination of its potential environmental and market impacts. Prior to that, however, the sale of some of these stocks contributed significantly to the supply of mercury on the domestic US-market, and to exports as well. US government sales were equivalent to 18 to 97 percent of the domestic US demand for mercury in the years 1990-94 (US EPA, 1997; Maxson and Vonkeman, 1996).

Uses of mercury

546. The element mercury has been known for thousands of years, fascinating as the only liquid metal, and applied in a large number of products and processes utilising its unique characteristics. Being liquid at room temperature, being a good electrical conductor, having very high density and high sur-

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[9] Including most of the parties to the OSPAR and HELCOM Conventions. OSPAR recommends a phaseout of the mercury cell chlor-alkali process within the territories of its parties. Most OSPAR and HELCOM countries are member states of the European Union.

face tension, expanding/contracting uniformly over its entire liquid range in response to changes in pressure and temperature, and being toxic to micro-organisms (including pathogenic organisms) and other pests, mercury is an excellent material for many purposes.

547. In the past, a number of organic mercury compounds were used quite broadly, for example in pesticides (extensive use in seed dressing among others) and biocides in some paints, pharmaceuticals and cosmetics. While many of these uses have diminished in some parts of the world, organic mercury compounds are still used for several purposes. Some examples are the use of seed dressing with mercury compounds in some countries, use of dimethylmercury in small amounts as a reference standard for some chemical tests, and thimerosal (which contains ethylmercury) used as a preservative in some vaccines and other medical and cosmetic products since the 1930's. As the awareness of mercury's potential adverse effects to health and the environment has been rising, the number of applications (for inorganic and organic mercury) as well as the volume of mercury used have been reduced significantly in many of the industrialised countries, particularly during the last two decades.

Examples of uses of mercury

As the metal (among others):

- for extraction of gold and silver (for centuries)
- as a catalyst for chlor-alkali production
- in manometers for measuring and controlling pressure
- in thermometers
- in electrical and electronic switches
- in fluorescent lamps
- in dental amalgam fillings

As chemical compounds (among others):

- in batteries (as a dioxide)
- biocides in paper industry, paints and on seed grain
- as antiseptics in pharmaceuticals
- laboratory analyses reactants
- catalysts
- pigments and dyes (may be historical)
- detergents (may be historical)
- explosives (may be historical)

548. The submissions received for the Global Mercury Assessment have confirmed, however, that many of the uses discontinued in the OECD countries are still alive in other parts of the world. Several of these uses have been prohibited or severely restricted in a number of countries because of their adverse effects on humans and the environment. Furthermore, while this chapter provides a good general picture of mercury production and use around the world, it also shows that it is crucial to gain an even better understanding of global mercury markets and flows in order to assess demand, to design appropriate pollution prevention and reduction measures, and to monitor progress towards specific objectives.

549. Parts of the descriptive text in this chapter were based on the submission from the Nordic Council of Ministers (sub84gov).

7.2 Global production

7.2.1 Production of primary mercury

550. Estimates for global primary production of mercury, as reported by the US Geological Survey, are given in table 7.2. Reese (1999) notes, however, that most countries do not report their mercury production, resulting in a high degree of uncertainty on the presented world production numbers.

Sznopek and Goonan (2000) quote alternative production estimates from Gobi International (1998). For 1990, global production was estimated at 4100 metric tons according to USGS and 5356 metric tons according to Gobi. For 1996, the USGS reported the production as 2795 metric tons and Gobi reported it as 3337 metric tons. The causes for these deviations are not known, but they indicate that the real production numbers may be higher than those presented in table 7.2. It may also be possible that recycled mercury, mercury recovered as a by-product or marketing from stocks have influenced the higher set of numbers.

551. Lawrence (2000) has estimated that on a worldwide basis, the amount of by-product mercury might be as much as 400 metric tons.

552. At the US EPA-sponsored Mercury Conference in Boston in May 2002, Lawrence (2002, as quoted by USA; comm-24-gov) estimated current supply to the world market at about 2000 metric tons, of which virgin mercury extraction (including by-product) accounted for about 1,000 metric tons annually, and another approximately 1,000 metric tons comes from other sources). In the current situation with low – and possible poorly reported - production numbers, such estimates may be highly uncertain.

Table 7.2 Estimated world production of primary (mined) mercury (metric tons), as reported by the US Geological Survey (Jasinski, 1994; Reese, 1997; 1999; unless noted; aggregation as presented in the Submission from the Nordic Council of Ministers, sub84gov) and by Hylander & Meili (2002) for the year 2000.

Country	**1981-1985 *1**	**1986-1989 *1**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Algeria	386-877	587-764	637	431	476	459	414	292	368	447	224	200	240
China	800	850-1200	1000	760	580	520	470	780	510	830	230	200	200
Finland ***2**	65-130	135-160	141	74	85	98	89	90	88	63	80	80	45
Kyrgyzstan	-	-	-	-	300	1000	379	380	584	610	620	620	600
Mexico	221-394	124-651	735	340	21	12	12	15	15	15	15	15	25
Russia	-	-	-	-	70	60	50	50	50	50	50	50	-
Slovakia /Cz	144-158	131-168	126	75	60	50	50	0	0	0	20	0	0
Slovenia	-	-	-	-	7	?	6	0	5	5	5	0	0
Spain	1416-1560	967-1471	-	-	-	643	393	1497	862	863	675	600	237 ***3**
Tajikistan	-	-	-	-	100	80	55	50	45	40	35	35	40
Ukraine	-	-	-	-	100	50	50	40	30	25	20	-	-
USA	570-962	140-520	562	58	64	w	w	w	65	w	-	-	15
USSR	1600-1700	1500-1650	800	750	-	-	-	-	-	-	-	-	-
Yugoslavia	0-88	51-75	37	9	-	-	-	-	-	-	-	-	-
Other countries	200-400	100-200	-	-	-	-	223	200	-	-	830	380	448
Totals for reported activity (rounded)	5500-7100	4900-6700	4000	2500	1900	3000	2200	3400	2600	2900	2800	2200	
Derived by Hylander & Meili (2002)	5600-6100	6100-6600	6100	3700	3100	3000	2000	3300	2800	2500	2000	2100	1800

Notes and legend:

w Withheld in the references

\- Not relevant or not available

/Cz Up to 1992 as part of Czechoslovakia

1 Reference: Metallgesellschaft (1992), as cited by OECD (1994). This reference's totals for 1990 and 1991 were 400-900 metric tons higher than the presented totals from USGS.

2 Numbers for Finland from 1990-1997 are from Finnish Environment Institute (1999).

3 Spain has reported a production in 2000 of 237 metric tons from the Spanish mercury mines.

7.2.2 Recycling of mercury

553. Recycled mercury has played an important role on the global market in recent decades. In 1982, the OECD estimated that the secondary production could be as much 40 percent of the primary production (OECD, 1985). Masters (1997) stated that 700 - 900 metric tons (20,000-25,000 "flasks"[10]) of mercury are recycled globally every year, of which some 200-400 metric tons originate from spent mercury-containing products, and the rest come mainly from chlor-alkali facilities. As mentioned in section 7.2.1 above, recent estimates (Lawrence, 2002) indicate that as much as 50 percent of the global supply may originate from secondary sources (sources other than virgin mercury extraction).

554. A large "reservoir" of mercury is known to be contained in products still in use, and "on the users' shelves" in society. If properly collected, recycled and managed, this reservoir could be the source of all of society's needs for mercury for many years into the future. Attempts have been made to quantify these reservoirs of mercury in Sweden, the Netherlands and Denmark.

555. In 1996, recycling of mercury in the USA, by itself, was greater than reported industrial usage in the same country (372 metric tons), and almost in the same range as the amount entering applications (417 metric tons; source: Sznopek and Goonan, 2000). Reported recycling numbers increased steadily from about 100 metric tons in 1990 to about 400 metric tons in 1996/97 (US EPA, 1997; USGS at www.usgs.gov; more recent trends were not investigated here).

556. German recycling of mercury has been quantified by Rauhaut (1996) for the period 1972-1993. In the years 1986-1993 (for which consumption is presented in the reference), the amounts of mercury re-refined for recycling in Germany were equivalent to 3-53 percent of the domestic mercury consumption in that country. During this period, recycling increased slightly (from 7 metric tons in 1986 to 36 metric tons in 1993), while German consumption decreased from 222 metric tons in 1986 to 67 metric tons in 1993. Recycling reached a maximum of 205 metric tons/year in the late 1970's. Reduced consumption and dropping mercury prices appear to have been among the possible reasons for the decrease in German recycling since the 1970's (Rauhaut, 1996).

557. For Denmark, an average of 3.5-4 metric tons of mercury was sent abroad for recycling per year in the years 1992-93 (Maag *et al.*, 1996).

558. In the Netherlands, 93 metric tons of mercury was recovered/recycled in 1995, including 2 tons product waste from Dutch use of amalgam fillings, 6 tons from Dutch gas sludge/waste, and 85 tons of mercury from imported sludge/waste (Maxson and Vonkeman, 1996; Annema *et al.,* 1995; DHV, 1996). One should note that recovery of mercury from, for example, gas sludge is not the same as recycling of spent mercury in products; rather it is a treatment of waste from resource extraction. When the mercury is marketed, it is equivalent to the by-product mercury produced during gold or zinc mining.

559. In an assessment of mercury in wastes in France, it was estimated that recycled mercury in that country was only about 2.8 metric tons/year. However, potentially significant wastes from chlor-alkali production, electrical contacts and laboratories, among others, were not included in the assessment (Groupe de travail de l'AGHTM, 1999).

560. Switzerland recovers about 15 metric tons recycled mercury/year (Swiss submission, sub38gov).

7.2.3 Price levels for metallic mercury

561. According to the US Geological Surveys' Mineral Yearbooks of various years (Reese, 1997; 1999; and others), mercury metals prices (i.e. selling prices quoted by dealers to customers) fluctuated quite dramatically during the early 1990's, averaging about 190 US$ per "flask" during the period 1990-1996 (range 122-262 US$). As one "flask" equals 34.5 kg, the average price per kg was 5.5 US$ at that time. During the years 1997-2000 the market price appeared stable at around 140-160 US$/flask (aver-

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[10] Named for the leather container in which mercury was originally traded. Each flask (nowadays in fact a steel container) contains 34.5 kg of mercury.

age 148 US$/flask or 4.3 US$/kg). The highest mercury prices in the 20th century were about 500 US$/flask during the last half of the 1960's. When expressing prices as adjusted for inflation in the US$, market prices in 1998 were only about one-tenth of the price in the late 1960's (Scoullos *et al.*, 2000).

7.3 Current use patterns

7.3.1 Global consumption

562. The global consumption equals the amount of mercury originating from the sources listed in section 7.1 above to final users/consumers, corrected for intermediate stock changes. No precise data on the total global consumption and its distribution among countries and applications is available. A great deal of mercury use in developing countries takes place beyond mainstream society, and therefore beyond the classical compilation of economic statistics - principally in small-scale, artisanal mining of gold and silver. Yet this use may be among the largest on a global basis. Thus, estimates of total world use of mercury must rely in part on uncertain estimates from very incomplete data. Data on use in OECD nations is more precise, yet as the market in these nations has shrunk with increasing public scrutiny, this information is both diminishing in relative importance and becoming less reliable.

563. Submitted data on national consumption are presented in table 7.3. Many governments did not submit data on consumption, although their submissions indicated consumption of mercury within a number of applications and uses. In cases where actual consumption data were not submitted, data on imports and/or production were presented here as rough indicators of consumption levels. It should be noted, however, that import and production data may not always mirror consumption levels, as other factors may influence the numbers. A more thorough analysis of these aspects would be valuable, but could not be accomplished for use in this report due to time and resource limitations.

Table 7.3 Submitted national data on consumption (or imports and production data, if consumption data were not available). Note that the basic assumptions and quality of data behind these numbers varies, and not all contributions are reported in all cases. Metric tons/year unless noted.

Country	Reported annual consumption (or import) Metric tons/year unless noted	Year(s)	Reference
Australia	>30 tons metallic mercury imported + 5 tons produced as by-product + 4 tons import of mercury compounds	1996	National submission, sub63gov
Canada	2.8-2.9 tons consumption, metallic mercury (of 9.4-11.4 tons imported)	1998-1999	National submission, sub42gov
Denmark	1.5 tons total consumption (including with products, domestic and imported)	2000/2001	Submission from the Nordic Council of Ministers, sub84gov
Finland	App. 10 tons comsumption (mercury produced as by-product, see table 7.2)	1991	National submission, sub44gov
France	45 tons net import averaged over 3 years (2, 112 and 20 tons respectively)	Averaged over 1998, 1999 and 2000 (individual years in brackets)	Comments from France, comm-10-gov
India	170-190 tons imports of metallic mercury	Not mentioned (presumably relatively recent estimate)	National submission sub71govatt1
Norway	0.8-1.4 tons consumption with products only, additional consumption as metallic mercury	1995/1999	Submission from the Nordic Council of Ministers, sub84gov
Peru	30-45 tons import of metallic mercury + 19-48 tons produced as by-product + small import of compounds	1998-2000	National submission, sub47gov

Country	Reported annual consumption (or import) Metric tons/year unless noted	Year(s)	Reference
Philippines	55.658 tons import of metallic mercury 26.169 tons import of metallic mercury 19.100 tons import of metallic mercury	1999 2000 2001	National Statistics Office & Bureau of Export Trade Promotion, DTI Philippines (comm-4-gov)
Sweden	2 tons consumption with products only, additional consumption as metallic mercury	1997	Submission from the Nordic Council of Ministers, sub84gov
Switzerland	30 tons import (uncertain estimate)	"Late 1990's"	National submission, sub38gov
Thailand	12,1 tons import of metallic mercury 17.2 tons import of metallic mercury 5.8 tons import of metallic mercury (mostly for fluorescent lamp production, and a little for dentistry and lab analysis)	2000 2001 Jan.-June 2002	National submission, sub53gov, www.customs.go.th (2805.40)
Turkey	4.5 "of mercury and its compounds imported"	2000-2001	National submission, sub34gov
USA	372 tons consumption, including with products produced in the USA (not imports)	1996	Sznopek and Goonan, 2000

564. Regarding the geographical distribution of global mercury consumption, Scoullos *et al.* (2000) quotes Lawrence (1994) for the information presented in table 7.4 on world mercury consumption and its distribution over various countries/regions.

Table 7.4 Estimated world mercury consumption in 1993 in metric tons, according to Lawrence (1994).

Country/region	Consumption
CIS	1379
USA	558
Europe	448
People's Republic of China	345
India	345
Iran *	414
Others	345
Total	3834

CIS - Commonweath of Independent States (former Soviet Union minus Baltic States).

* According to Hylander (2001), the large consumption by Iran in 1993 was due to the restarting of a chlor-alkali plant destroyed during the war - consumption was not so large in other years.

Estimated global distribution of consumption among regions and uses

565. Sznopek and Goonan (2000, as quoted in the submission from the Nordic Council of Ministers, sub84gov) have developed estimates of the likely distribution of global consumption and uses of mercury among diverse regions and uses. According to this analysis, the industrialised countries are still by far the largest users of mercury, in agreement with the numbers presented by Lawrence in table 7.4.

566. An estimate of the distribution of global mercury consumption by application group is shown in table 7.5. Taken together with table 7.4, this table shows that Western Europe and North America accounted for about 60 percent of the mercury consumed by worldwide chlor-alkali production, although these numbers were extrapolated from consumption ratios for this industry in the USA in the early 1990's, and no longer show a realistic picture of the actual situation. Based on data reported to their

respective governments by the industry, US- and OSPAR-region[11] (refer to section 9.3.2 for further details concerning OSPAR) chlor-alkali facilities consumed in 1999/2000 about 170 metric tons of mercury per year: 28 metric tons in the USA, and 145 metric tons in the OSPAR countries. Based upon diverse reports from other parts of the world, total mercury consumption by the chlor-alkali industry in the rest of the world is significantly higher.[12]

567. Western Europe, North America and Northeast Asia together accounted for about 80 percent of the global amount of mercury used for manufacturing of products. The calculations for product manufacturing are deemed indicative only (in submission from the Nordic Council of Ministers, sub84gov), as they were based on US consumption patterns in 1990 and 1996, and the assumption that consumption can be described as a function of "economic sophistication". That is, the numbers were not based on any actual observations of mercury consumption in product manufacturing in countries other than the USA.

568. Finally, as mentioned in the notes to table 7.5, mercury consumption for gold extraction in the table was estimated only for Brazil. The notes provide indications of the magnitude of global consumption.

Table 7.5 Estimates of global mercury consumption by application category in 1990 and 1996 respectively, according to Sznopek and Goonan (2000, as presented in the submission from the Nordic Council of Ministers, sub84gov).

Application category	**1990**	**1996**
Chlor-alkali production	2003	1344 ***3**
Use in products	1818	1061
Small-scale gold mining in Brazil***1**	200	100
Addition to stocks ***2**	1335	832
Total	**5356**	**3337**

Notes: 1 One estimate of global mercury releases (obviously related to gold production, which is in turn related to gold demand) from small-scale gold mining was up to 460 metric tons per year for the late 1980's/early 1990's (Lacerda, 1997a). An estimate for global consumption of mercury was 350-450 metric tons/year for 1996 (Maxson and Vonkeman, 1996 – as cited by Scoullos *et al.,* 2000). A more recent small-scale mining estimate for global consumption of mercury was at least 500 metric tons, and possibly 1000 metric tons per year.[13]

2 It was assumed by Sznopek and Goonan that this category also includes amounts for which the use is unknown ("buffer category" in the calculated global mercury balance).

3 Recent estimates of global mercury consumption by the chlor-alkali industry (note that consumption is not equivalent to emissions) are significantly lower, as indicated in the text above. See also section 7.4.1.

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[11] OSPAR member countries are Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom, although Denmark and Luxembourg have no chlor-alkali production, and Ireland and Norway have no mercury-cell chlor-alkali production. Of European Union member states, only Austria, Greece and Italy are not Parties to the OSPAR Convention.

[12] It should be noted that chlor-alkali mercury "consumption" figures should not be taken as equivalent to releases to the environment. This is because some of the mercury "consumption" (i.e. purchases corrected for inventory change) can ultimately be recovered from sludge wastes during normal operation, plant equipment and structures during major maintenance and, especially, when the mercury cellrooms are decommissioned (see also section 7.3.2. below). There is concern, however, that in some countries this recovery is inadequate.

[13] MMSD ("Case studies," 2002) calculated global gold mine production in 2000 as 2574 metric tons, and estimated that 20 percent of this comes from artisanal and small miners, most of them using a mercury process to recover gold. This is consistent with Gold Fields Mineral Service Limited (World gold production, 1998) estimate of global gold production by artisanal miners of 500 to 800 tons. Since artisanal miners on average use between one and two kilograms of mercury for each kilogram of gold produced (Lacerda, 1997b), this suggests world mercury use in gold mining of at least 500, and possibly 1000 tons per year. If one were to include artisanal mining of silver as well, the estimate of mercury use would be considerably higher.

7.3.2 Uses of mercury

569. Table 7.6 gives an overview of identified intentional applications of mercury and the available information on their current use. The applications marked as “general” in the table were mentioned in many of the submissions, as well as in current reviews. For applications that differ from the general pattern or were considered largely abandoned, the countries mentioning such uses are listed in the table. For some applications, the submitted information on bans and restrictions (see table 7.7) is the best available indication of current use. Applications that are known to have been used historically, but for which no confirmation of their current use was provided in submissions, are marked “no confirmation of current use”. Finally, for some applications, less certain indications of current use were added, based on the background knowledge of the authors.

570. It is important to note that this list of uses also indicates where to search for mercury sources nationally or locally, for example in an effort to identify and reduce or eliminate specific sources of mercury in environmental media, waste or waste water. All of these uses gives rise to mercury releases in one or more of the phases of their life cycles: mercury extraction, product manufacturing, use, disposal, recovery and intermediate transport.

571. It is important to investigate national and global use patterns further - for example, in order to better assess patterns in global consumption of mercury, as a basis for possible international initiatives. However, this has not been possible within the time and resource constraints imposed on this phase of UNEP’s mercury assessment process.

572. Examples of the relative contributions of different uses to total mercury consumption is given for selected countries in tables 7.8 and 7.9 in section 7.3.3 below.

Table 7.6 Identified mercury applications, and indications of their current use.
(This table attempts to reflect the actual situation in the countries listed, although it should not be assumed to be exhaustive or complete.)

Application	**Indications of current use**
Chlor-alkali production (chlorine and caustic soda)	General
Dental amalgam	General
Artisanal gold and silver mining	Australia, Burundi, Brazil, Burkina Faso(?), China, Costa Rica, Colombia, Côte d’Ivoire(?), Ecuador, Colombia, French Guyana, Ghana, Indonesia, Mongolia, Panama, Papua New Guinea, Peru, Philippines, Russia, Tanzania, Venezuela, Vietnam, Zimbabwe
Batteries	In use, but banned or restricted in many countries
Measuring and control equipment	See below
Medical thermometers	General, but banned or restricted in a few countries
Other thermometers (marine engine control, laboratory)	General, but banned or restricted in a few countries
Blood pressure gauges (sphygmomanometers)	General, but banned or restricted in a few countries
Industrial and meteorological manometers	Most likely general, but banned or restricted in a few countries
Pressure valves (district heating systems, industry)	Banned or restricted in a few countries
Gyroscopes	Banned or restricted in a few countries
Electric and electronic switches	Banned or restricted in a few countries
Level switches (sewer pumps, door bells, railway signals, car boot lids, refrigerators, freezers, fall-alarms for the elderly, etc.)	Banned or restricted in a few countries
Multiple poled switches (for example in excavation machines)	Banned or restricted in a few countries

Application	**Indications of current use**
Mercury-wetted microelectronic switches	Most likely general
Thermo-switches	Banned or restricted in a few countries
Switches in sports shoes with lights in soles	Banned or restricted in a few countries
Discharge lamps	General
Fluorescent lamps	General
Other mercury-containing lamps	General
Laboratory chemicals, electrodes and apparatus for analysis	General
Pesticides (seed dressing and/or others)	Australia, Belarus, Benin (unspecified), Burkina Faso (unspecified), Côte d'Ivoire, Ghana, Guinea (unspecified), India (unspecified), Ireland
Biocides for different products and processes	Cameroon (unspecified industrial production), Ireland
Paints (latex paints and possibly others)	Australia, Ghana, Guinea, India, Ireland, Samoa, Thailand (substitution ongoing), Trinidad and Tobago (subst. ongoing or completed recently)
Slimicides for paper production	Morocco,
Pharmaceuticals (biocide or systemic functions)	Czech Republic (unspecified), Ghana (unspecified), India, Australia (unspecified and for horses), Switzerland
Preservatives in vaccines	In use
Preservatives in eye drops	Most likely still in use
Disinfectants, e.g. in hospitals	Burkina Faso (unspecified)
Herbal medicine, "folk" medicine, "street pharmacies"	India (some herbal medicines), Lesotho (metallic mercury)
Catalytic mercury compounds	India
Catalysts for polyurethane/other polymer production	Finland, Australia, Ireland
Catalysts in acetylene-based production of vinyl chloride monomer, vinyl acetate, and acetalydehyde	(Used previously in a large number of factories worldwide) No confirmation whether or not this use continues.
Cosmetics (creams, soaps)	Benin (unspecified), Ireland (unspecified)
Skin lightening creams and soaps	In common use, restricted in some countries
Biocides in eye cosmetics	Possibly in use, restricted in some countries
Lighthouses (marine use; for stabilising lenses)	Canada (possibly general – mentioned in the literature)
Production of counterfeit money	Cameroon (no details on how mercury is used in the process)
Religious ceremonies "superstitious" activities	USA and possibly Caribbean regions (US ATSDR, 1999), Lesotho
Pigments	No confirmation of current use
Tanning	Ireland
Browning and etching steel	Ireland
Colour photograph paper	Australia
Explosives, fireworks	No confirmation of current use
Airbag activators and anti-lock braking system (ABS) mechanisms in cars	No confirmation of current use
Artisanal diamond production	Guinea ("to clean stones and improve physical quality")
Recoil softeners for rifles	Ireland
Arm and leg bands (e.g. for "tennis elbow")	Ireland
Executive toys	Ireland
Surfacing material used in running tracks in sports stadiums ("Tartan" tracks)	Historical use in Switzerland
Ammunition	Historical use in Switzerland

Table 7.7 Information on national actions, both regulatory and voluntary, to eliminate or restrict uses of mercury presented in table 7.6 (derived from a separate appendix to this report: "Overview of existing and future national actions, including legislation, relevant to mercury").

Application	**Import, sale and/or use banned or restricted nationally** (see separate appendix)
Chlor-alkali production (chlorine and caustic soda)	Japan
Gold extraction	Brazil, China, Philippines
Mercury-containing products in general (with some exemptions)	Denmark, Sweden, Switzerland
Dental amalgam	Denmark, France, New Zealand, Norway, Sweden, Switzerland
Batteries	Canada, China, Estonia, European Union countries*, Hungary, Mauritius, Norway, Slovak Republic, Switzerland, Turkey, USA,
Mercury-oxide batteries	European Union countries*, Japan
Alkaline batteries	Canada, European Union countries*
Other batteries (zinc-oxide, silver-oxide, mainly button cell formats)	Canada, European Union countries*
Measuring and control equipment	Sweden (in general)
Medical thermometers	Canada, Denmark, France, Norway, Sweden,
Other thermometers (marine engine control, laboratory)	Denmark, Sweden
Blood pressure gauges	
Industrial and meteorological manometers	Denmark
Pressure valves (district heating systems, industry)	Denmark
Gyroscopes	Denmark
Electric and electronic switches	Denmark, Sweden, Switzerland
Level switches (sewer pumps, door bells, railway signals, car back lids, refrigerators, freezers, fall-alarms for old people, etc.)	Denmark, Sweden
Multiple poled switches (for example in excavation machines)	Denmark
Mercury-wetted microelectronic switches	
Thermo-switches	Denmark
Switches in sports shoes with lights in soles	Denmark
Discharge lamps	
Fluorescent lamps	Canada, Sweden, European Union countries* from 1 July 2006
Other mercury-containing lamps	Denmark, Sweden
Laboratory chemicals, electrodes and apparatus for analysis	Denmark, Sweden
Pesticides	
Seed dressing and/or other agricultural uses	Armenia, Burundi, Canada, China, Colombia, Cuba, Czech Republic, European Union countries*, Hungary, Japan, Latvia, Lesotho, Lithuania, Mauritius, Norway, Samoa, Switzerland, Tanzania, USA
Biocides for different products and processes	Denmark, Japan, Sweden, Switzerland
Paints (latex paints and possibly others)	Cameroon, Costa Rica, European Union countries*, Japan, Norway, Switzerland, USA
Preservation of wood	European Union*, Norway
Pharmaceuticals (biocide or systemic functions)	Austria, Canada, Costa Rica, Denmark, Japan, Mauritius,

Application	**Import, sale and/or use banned or restricted nationally** (see separate appendix)
	Sweden, Switzerland, USA
Preservatives in vaccines	
Preservatives in eye drops	
Disinfectants, e.g. in hospitals	Denmark
Herbal medicine, "folklore" medicine, "street pharmacies"	Denmark
Catalytic mercury compounds	
Polyurethane (PUR) **and other polymer production	
Cosmetics (creams, soaps)	China, European Union countries*, Norway
Skin lightening creams and soaps	Cameroon, Denmark, USA, Zimbabwe
Biocide in eye cosmetics	
Production of counterfeit money	
Religious ceremonies and so-called "superstitious" activities	
Pigments	Denmark
Explosives, fireworks	Denmark
Airbag activators and anti-lock braking system (ABS) mechanisms in cars	European Union countries*
Artisanal diamond production	
Packaging and packaging waste	European Union countries*, Norway

Note - * This implies that there is European Community legislation that applies to all member States of the European Union, namely Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

7.3.3 Examples of national consumption distributed among uses over time

Table 7.8 Consumption of mercury (metric tons/year) in deliberate applications in Denmark at present, 10 years ago and 20 years ago (as described in the submission from the Nordic Council of Ministers, sub84gov).

Year/use	**1982/83 *1**	**1992/93 *1**	**2000/2001 *1**
Chlor-alkali production	3.00	2.50	0
Dental amalgam	3.1	1.80	0.9
Mercury-oxide batteries	2.40	0.36	0
Other batteries	2.30	0.28	0 ***2**
Measuring and control equipment	0.53	0.50	0.3
Electric and electronic switches	0.34	0.30	0 ***2**
Light sources (lamps)	0.14	0.17	0.17
Medical thermometers	0.75	0.05	0
Other thermometers	1.55	0.10	0
Laboratory chemicals	0.50	0.09	0.09
Other intentional uses	1.48	0.03	0.03
Total, intentional uses	16.09	6.18	1.5

Notes:

1 Includes mercury in net imports of products. 1982/83 numbers are from Hansen (1985) and 1992/93-numbers from Maag *et al* (1996). 2001-numbers are rough estimates based on background knowledge and knowledge of elimination of uses in response to the Danish mercury ban by Heron (2001) and Maag in the submission from the Nordic Council of Ministers, sub84gov.

2 Some mercury may be present in button cell batteries, and in micro-switches in some types of electronics.

Table 7.9 Reported consumption ****1*** *of mercury in the USA in 1990 and 1996 (metric tons/year; Jasinski, 1994, and Sznopek and Goonan, 2000).* ****3***

Application	**1990**	**1996**
Dental	44	31
Laboratory	32	20
Measurement and control devices	108	41
Wiring devices and switches	70	49
Electric lighting	33	11
Paint	14	0
Batteries	105	0
Chlor-alkali production ***2**	247	136
Other	58	84
Total	711	372

Notes: 1 Imports and exports of mercury incorporated in products were not included in the numbers. Except for wiring devices and switches, which may be of some importance to the actual materials balance, Sznopek and Goonan (2000) deem that imports and exports are approximately equivalent or negligible.

2 Mercury consumption in the US chlor-alkali sector during 2001 was reported by industry at 28 metric tons (31 short tons), a 75 percent decline from consumption levels recorded during 1990-96.

3 Updated and more detailed information on use and mobilisation of mercury can be found in Stone (2002).

7.4 Particulars on chlor-alkali production and gold extraction

7.4.1 Chlor-alkali production and residual mercury

573. Chlor-alkali production has been among the largest intentional uses of mercury in the world (Sznopek and Goonan, 2000; see section 7.3.1), although emissions controls and, in particular, closing and converting facilities to non-mercury technology have led to a steady decrease in the consumption and releases of mercury in this industrial sector. In one of the three common processes for chlor-alkali production - the mercury cell process - large quantities of mercury serve as a liquid cathode in the electrolytic process. The process releases mercury to the environment with air emissions, water discharges and the sodium hydroxide (NaOH) and hydrogen products[14], and mercury-containing solid and liquid process wastes are generated that are carefully disposed of in some countries (mercury recovery, hazardous waste landfill), and less carefully in others (at the production site, normal landfill). Some of the mercury in the solid wastes is recovered and recycled to the production process – often as an on-site integrated part of the production facility. However, mercury must be periodically added to the process to replenish losses. Eventually, when mercury cellrooms close or are converted to a non-mercury process, large inventories of mercury may be recovered from process equipment and structures.

574. In recent decades, releases from the remaining mercury process chlor-alkali plants in Western Europe and the US have been reduced substantially, as a result of pollution-limiting efforts in a continued dialog between environmental authorities/international organisations and the industry. Little information has been found that suggests similar improvements in other parts of the world. Even after these improvements, the use of mercury in chlor-alkali production remains a significant source of mercury releases to the environment. Data provided by industry and reported by the US Toxic Release Inventory for 2000 (US EPA TRI Explorer report for chemicals facilities SIC 28, available at http://www.epa.gov), and the OSPAR Parties for 1999 (OSPAR, 2001b), indicated that total emissions (not including mercury in wastes) from these sixteen countries (which together account for approximately 62 percent of global mercury cell chlor-alkali capacity) amounted to about 16 metric tons per year during 1999/2000. Less detailed data is available from other regions, as mentioned below.

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[14] In poorly managed facilities, mercury in untreated hydrogen (often sent as fuel to on-site power stations) has been a major source of chlor-alkali mercury releases to the atmosphere, whereas mercury contamination of NaOH tends to be minor.

575. As one example, Qi *et al*. (2000) reported that mercury releases (including mercury in wastes – it is not described how these wastes were treated) from Chinese chlor-alkali plants decreased significantly from 500-1400 g of mercury/ton of sodium hydroxide production before 1977, to 160-180 g of mercury/ton of sodium hydroxide production in 1997, but were still much higher than in some other countries. Specifically, these 1997 Chinese releases were more than 4 times greater per ton of production, than OSPAR releases (including mercury wastes, which were stored or treated according to relevant legislation) at that time. However, most chlor-alkali plants in China use the diaphragm process, which does not use mercury, and plans for converting or closing the few remaining mercury-cell chlor-alkali facilities in China (we know of only one, owned by the Tianjin Chemical Company, with a capacity of 50 thousand metric tons chlorine per year) were mentioned in the presentation (Qi *et al*., 2000).

576. In a second example, the Mexican submission indicated that mercury releases from Mexican mercury-cell chlor-alkali plants (three sites identified, with a capacity of about 170 thousand metric tons chlorine per year) are also considerably higher than in similar plants in the USA.

577. Adequate and mature cleaner technology in the form of the non-mercury membrane chlor-alkali process is readily available and widely used all over the world. A third technology is available and in use, called the diaphragm process, but has been deemed slightly less beneficial than the membrane process. Scoullos *et al* (2000), EIPPCB (2000) and Lindley (1997) give comprehensive descriptions and discussions of the chlor-alkali mercury-process and its implications.

578. According to worldwide chlor-alkali production capacity statistics (see table 7.10), the regions of West and Central Europe have the highest relative percentage of mercury-cell chlorine production capacity in the world (61 and 66 percent in 1997, respectively), according to Sznopek and Goonan (2000), citing CMAI (1999). At the same time, the world average of mercury-based production was 24 percent of total production capacity, according to the same source, including about 15 percent in North America. According to updated information from the USA (comm-24-gov), mercury-cell production in 2001 has further decreased to 10 percent of the total US chlorine production. In Japan, all mercury chlor-alkali production has long ago been replaced by non-mercury technologies (CMAI, 1999; Maxson, 1999, as cited by Scoullos *et al*., 2000). As about three-fourths of the entire global chlorine production capacity is situated in Western Europe, North America and Northeast Asia, it is clear that a large part of the mercury at work in the world's chlor-alkali plants is located in Europe, although a large part of the mercury consumption and releases remain in less developed nations. Based on actual records of easily recoverable mercury from decommissioned chlorine production facilities in the EU and the US, it can be roughly estimated that about half (12,000-13,000 metric tons[15]) of the mercury inventories associated with chlor-alkali production in the world (roughly estimated at 20,000 - 30,000 metric tons[16]) is situated within the EU.

579. In 1990, a total phase-out of the mercury process for chlor-alkali production by the year 2010 was recommended by the Parties to the OSPAR Convention of the North European region (PARCOM Decision 90/3 of 14 June 1990; see section 9.3.2). Chlor-alkali facilities that come under the responsibility of OSPAR, most of whose Parties belong to the European Union, currently hold more than half of the mercury amounts working in European chlor-alkali production. Decision 90/3 recommending mercury cell phase-out was reviewed in 1999-2001, but no changes were made. Implementation of this recommendation is at the discretion of the national regulatory authorities of the various Parties to the OSPAR Convention. Therefore, conversions and closures of mercury-cell chlor-alkali plants are being carried out faster in some OSPAR countries than in others, but at a pace that will see most of these facilities phased out by 2020 (Maxson and Verberne, 2000).

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[15] Calculated by Maxson and Verberne (2000).

[16] Global mercury-based chlorine production capacity in 1997 was about 11,640,000 metric tons/year (Euro Chlor, 1998). Based on the data collected by Maxson and Verberne (2000) showing about 1,8 kg Hg (in cells) per metric ton of chlorine capacity, and another 10-15 percent easily recoverable from other parts of the plant, global mercury inventories associated with chlor-alkali production amount to over 25,000 metric tons. The range of 20,000-30,000 metric tons reflects some uncertainty, such as possibly lower efficiency rates in some regions.

580. The releases of mercury from chlor-alkali production are not the only issue of concern in relation to this use. Among OSPAR countries and in the EU there has been considerable discussion about the possible impacts the re-marketing of the mercury from decommissioned chlor-alkali facilities will have on the global mercury market. From the OSPAR countries this will amount to more than half of the 12,000-13,000 metric tons mentioned above. This mercury is virtually "pure" and therefore easily marketable, although there has been some debate as to whether this mercury should technically be considered to be "waste" and therefore covered by the transport restrictions imposed by the Basel Convention (see section 9.3.4). According to a very recent legal determination (European Commission, 2002), "the decommissioned mercury is not automatically governed by the Community waste legislation or by the requirements of the Basel Convention." This means that each member state of the EU, "according to individual circumstances," will determine whether or not this mercury is a "waste". Where such decisions find that the mercury is waste, the material will be covered by all applicable international agreements. In passing, the referenced document notes that final disposal of this mercury would be the "optimal solution" from an environmental point of view, and considers this solution to be the only sustainable approach.

581. Sweden has decided that such residual pure mercury should be considered as waste and is subject to Swedish legislation prohibiting exports of mercury waste. The OSPAR countries have proposed that safe measures for the disposition of this residual mercury should be discussed at the EU level, because individual national initiatives would affect trade parameters and waste handling policies within the Union, and would probably hinder the operation of the common market within the EU.

582. It is feared that large market releases of recycled mercury may render low-priced mercury more abundant on the world market and encourage more extensive or even revived use of mercury (in certain applications) in countries with less restrictive legislation, fewer enforcement possibilities and/or special social and economic circumstances. One example might be a slow-down in efforts to use mercury more efficiently in small-scale gold mining in the Amazon and other regions of the world (see below), which has been, at least partly, based on mercury imports from OECD countries (Maxson and Vonkeman, 1996, as cited by Scoullos *et al.*, 2000). Another specific example was the export of a complete, old chlor-alkali production plant, including mercury, from Denmark to Pakistan. The intervention of the Danish Minister of the Environment prevented the factory from actually being assembled in Pakistan, and the facilities were returned for disposal. Subsequently, in 1999 all West European chlor-alkali producers presented the authorities with a voluntary commitment, one clause of which commits them not to sell or transfer mercury cells after plant shutdown to any third party for re-use.

583. All these considerations parallel the discussions in the US, where concern for the environmental consequences led to a suspension of US federal mercury sales from government stocks in 1994 – a suspension still in effect (US EPA, 1997; Snopek and Goonan, 2000, as cited by Scoullos *et al.*, 2000).

584. In order to address the same issue of market disruption, as well as social responsibility, the European chlorine industry association (Euro Chlor) signed an agreement with the state-owned Miñas de Almadén of Spain, one of the world's most important mercury producers and marketers. This agreement stipulates that Miñas de Almadén will accept all surplus mercury from western European chlorine producers, under the condition that it displaces, ton for ton, mercury that would otherwise have been newly mined (referred to as "prime") and smelted to satisfy legitimate uses. All western European members of Euro Chlor have agreed to transfer their surplus mercury to Almadén (or, so as to honor free trade and competition, an alternative European mercury producer). Euro Chlor believes that central and eastern European producers may also be convinced to join the agreement. While this agreement clearly represents an effort by all parties to responsibly address the problem of surplus mercury, some people have the view that there are not yet adequate controls on where this mercury would be sold or how it would be used.

585. The World Chlorine Council has pointed out that this agreement is closely linked to the voluntary commitments presented in 1999 to the authorities by all West European chlor-alkali producers. The companies recognise that the pure mercury from cellrooms that close or are converted is best used in a manner that minimises the need for adding mercury to the global circulation by mining and extract-

ing virgin mercury. The companies also recognise that if in the future it appears that the supply of mercury from the chlor-alkali industry exceeds the legitimate remaining demand for mercury, storage options will need to be discussed.

586. As indicated, use of mercury for chlor-alkali production is not confined to the western world. For historical reasons, this technology is still used world-wide, though the relative share of the mercury technology is lower in other regions than in Europe. Table 7.10 gives an impression of the global and regional chlorine production capacity, and the relative share thereof based on mercury technology.

Table 7.10 Global and regional chlorine production capacity in 1992 and 1997, and the relative share thereof based on mercury technology (chlorine production capacity in metric tons; table from Sznopek and Goonan, 2000, citing CMAI, 1999).

	Total World	**North America**	**South America**	**West Europe**	**East Europe**	**FSU**	**Africa**	**Middle East**	**India Pakistan**	**N.E. Asia**	**S.E. Asia**
All Cells											
1992	45,394 100%	13,575 30%	1,696 4%	11,223 25%	1,896 4%	3,773 8%	535 1%	800 2%	1,523 3%	9,706 21%	667 1%
1997	49,437 100%	14,686 30%	1,787 4%	10,640 22%	1,791 4%	3,676 7%	584 1%	1,294 3%	2,135 4%	11,794 24%	1,050 2%
CAGR	1.72	1.59	1.05	(1.06)	(1.13)	(0.59)	1.77	10.10	6.99	3.94	9.50
Hg-Cell											
1992	12,625 100%	2,016 16%	460 4%	6,984 55%	1,437 11%	248 2%	295 2%	263 2%	898 7%	0 --	5 nil
1997	11,640 100%	1,809 16%	424 4%	6,445 55%	1,174 10%	248 2%	222 2%	276 2%	916 8%	50 nil	5 nil
CAGR*	(1.61)	(2.14)	(1.62)	(1.59)	(3.94)	0	(5.53)	0.97	0.40	nil	0
% Hg-Cell											
1992	28	15	27	62	76	7	55	33	59	0	1
1997	24	15	24	61	66	7	38	21	43	nil	nil

*CAGR=Compound Annual Growth Rate. Numbers in parentheses are negative.

587. Chapter 8 provides information on possibilities for substitution of mercury in chlor-alkali production, as well as technical possibilities for reduction of mercury releases from mercury-based chlor-alkali plants.

7.4.2 Revived mercury use in gold mining

588. An example of a revived application of mercury is the mercury amalgamation process for gold extraction, which has caused great worry among people concerned about mercury's global environmental impact. Lacerda (1997a) has described and reviewed the use of this technique and its resulting mercury burden to environment from both ancient and present-day exploitation. Mercury has been used in gold and silver mining since Roman times. With the invention of a refining method – the "patio" process – in Spanish colonial America, silver and gold were produced in large scale in America as well as in Australia, Southeast Asia and even in England. Mercury released to the biosphere due to this ancient activity may have reached over 260,000 metric tons in the period from 1550 to 1930, after which easily exploitable silver reserves were nearly exhausted, and the mercury amalgamation process was partly replaced by the more efficient large scale cyanidation process, enabling extraction of gold even from low-concentration ores. After this development, mercury amalgamation virtually disappeared as a significant mining technology until the 1970's.

589. Exceptional increases in gold prices, and the prevailing difficult socio-economic situation in the 1970's, resulted in a new gold rush, especially in the southern hemisphere, involving more than 10 million people on all continents. Presently, mercury amalgamation is used as the major artisanal technique for gold extraction in South America (especially the Amazon), China, Southeast Asia and some African countries. In Brazil mercury amalgamation was used for the production of 5.9 metric tons of gold in

1973. In 1988, this figure had increased to over 100 metric tons per year. During the 1990's this figure decreased again due to falling gold prices and exhausted deposits (Uppsala University; comm-3-ngo).

590. Although alternative extraction methods existed, the amalgamation method was probably chosen as the one requiring the lowest start-up investments and very little technical know-how.

591. The list of countries where the mercury amalgamation process is reportedly used for gold extraction in recent years includes Brazil, Venezuela, Bolivia, French Guyana, Peru, Ecuador, Colombia, Philippines, Indonesia, Vietnam, China (Lacerda, 1997a), Panama, Papua New Guinea, Ghana, Zimbabwe (Maxson, 1999, as cited by Scoullos *et al.*, 2000), Tanzania (Appel *et al.*, 2000), and Russia (Laperdina *et al.*, 1996). From information submitted as comments to drafts of this report (see table 7.6), the following countries can be added to the list: Australia, Burundi, Burkina Faso, Costa Rica, Côte d'Ivoire, India, Kyrgyz Republic, Mali, Mexico, Mongolia, Mozambique, South Africa and Suriname.

592. In China, over 200 small mines were said to have been opened since 1992 in one province after permission to form individual enterprises was granted. This induced an increment in gold production of 10 percent, according to Yshuan (personal communication, in Lacerda, 1997a). This may be one explanation for the relatively high mercury imports to China pointed out by Sznopek and Goonan (2000), and Scoullos *et al.* (2000). During the last couple of years, however, all artisanal mining of gold (and mercury) has been forbidden by the Chinese authorities.

593. Lacerda (1997a) has estimated the yearly global releases of mercury to the environment from gold extraction at up to 460 metric tons/year in the late 1980's/early 1990's, equivalent to about 10 percent of the total global anthropogenic releases. Certain areas of the Amazon basin are extensively contaminated with mercury as a result of small-scale gold mining. The gold amalgam from the extraction process releases mercury as vapour when heated in one of the steps in the purification. Mercury is found not only in mine tailings at extraction sites and at trading posts, but also in soil, plants, sediments and waterways. It was estimated in the early-mid-1990's that at least 95 percent of the mercury used was lost to the environment, where it contributed to the continuing global atmospheric re-mobilisation and cycling of mercury (Maxson and Vonkeman, 1996, as cited by Scoullos *et al.*, 2000). Cited by the same authors, Greenpeace (1994) estimated the total world-wide consumption of mercury for gold mining at 400-500 metric tons/year in 1993-94, but some industry observers consider this estimate too high, and suggest that the 1996 consumption may have been 350-450 metric tons/year. Other well-informed analysts (MMSD, 2002) consider the number too low, and suggest that at present 500 to 1000 metric tons annually may be consumed by artisanal gold and silver miners, of which a very high percentage is lost to the environment. Maxson and Vonkeman (1996), as cited by Scoullos *et al.* (2000), have noted that considerable amounts of this mercury have been supplied from or via Europe over the years.

594. During 1989, gold miners in Brazil released at least 168 metric tons of mercury into the environment. This corresponds to 80 percent of the total loss of mercury in Brazil in 1989 (estimated at 210 metric tons). The second largest source, Brazilian chlor-alkali production, was responsible for 8 percent of the releases. The final destination of another 67 metric tons is not known, and according to Hylander *et al* (1994), citing CETEM (1992), it is possible that this amount also ended up in the gold mining process, hence increasing the possible total loss of mercury from this source to 277 metric tons in 1989.

595. Maxson and Vonkeman (1996), as cited by Scoullos *et al.* (2000), noted that the sale and use of mercury for gold mining are officially banned in Brazil, but this ban is clearly difficult to enforce in the Amazon. According to this source, mercury imports for this use still continue, mainly from neighbouring countries like Colombia and Venezuela, but from Europe as well (mercury is traded globally). In recent years mercury use for this purpose is reported to be falling, mostly because the reserves of gold accessible to small-scale gold mining ("garimpeiro") techniques seem to be disappearing (Mercury as a Global Pollutant, 1999). According to data produced by Brazil's National Department of Mines and Prospecting, Brazil produced 112.5 metric tons of gold in 1988, of which small-scale gold miners were responsible for 90 metric tons. In 1995 the total gold output was reported at only 63 metric tons, of which 20 were produced by small-scale gold miners. Maxson and Vonkeman (1996), as cited by Scoullos *et al* (2000) caution that such numbers should be interpreted loosely, as many of these activities are

beyond government control. Maxson and Vonkeman (1996), as cited by Scoullos *et al*. (2000), cited CETEM (1993) for import numbers for mercury estimated at 250 metric tons in 1992, of which 150 metric tons were used in mining. This figure is thought to have declined to approximately 100 tons in 1996 in combination with a lower gold price than during the 1980's.

596. Maxson and Vonkeman (1996), as cited by Scoullos *et al*. (2000), noted that the mercury price is clearly not the determining factor in its use in artisanal gold mining. The price would need to be considerably higher to stimulate any wide-spread use of mercury-saving technology in small-scale mining.

597. In several South American countries, there are examples of programmes to promote less polluting mercury-based extraction equipment, raise awareness of mercury's hazardous qualities and provide other help and information regarding environmental and social aspects, business administration etc. Some projects are also assessing or trying to enhance the authorities' (and other interested parties') possibilities and capabilities to enforce environmental regulation in small-scale gold mining areas (based on Mercury as a Global Pollutant, 1999). A UNIDO-GEF global action plan to remove barriers to the introduction of cleaner artisinal gold mining technologies is also being implemented in a number of countries on three continents, see section 9.4.6.

598. According to Uppsala University of Sweden, an additional environmental hazard may often follow after gold extraction by the relatively inefficient amalgamation practices used by most artisanal miners. Since considerable amounts of gold remain on mining sites after amalgamation, e.g. in Brazil, the leftovers are often reprocessed using the cyanide process (Hylander, 2001). Cyanide is also an environmental toxin, but possesses one important advantage over mercury as it is degradable and does not bioaccumulate.

599. Chapter 8 provides information on possibilities for preventing or reducing mercury releases from artisanal gold extraction.

8 Prevention and control technologies and practices

8.1 Overview

600. This chapter summarizes information submitted from around the world about prevention and control technologies and practices, and their associated costs and effectiveness, that could reduce and/or eliminate releases of mercury, including the use of suitable substitutes, where applicable.

601. As noted in chapter 6, the sources of releases of mercury to the biosphere can be grouped in four major categories (including the last category, that is not clearly explained in many reviews of the subject):

- Natural sources - releases due to natural mobilisation of naturally occurring mercury from the Earth's crust, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of mercury impurities in raw materials such as fossil fuels – particularly coal, and to a lesser extent gas and oil – and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;
- Re-mobilisation of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles.

602. Figure 8.1 shows graphically these primary release categories, together with the main alternatives for preventing and controlling releases.

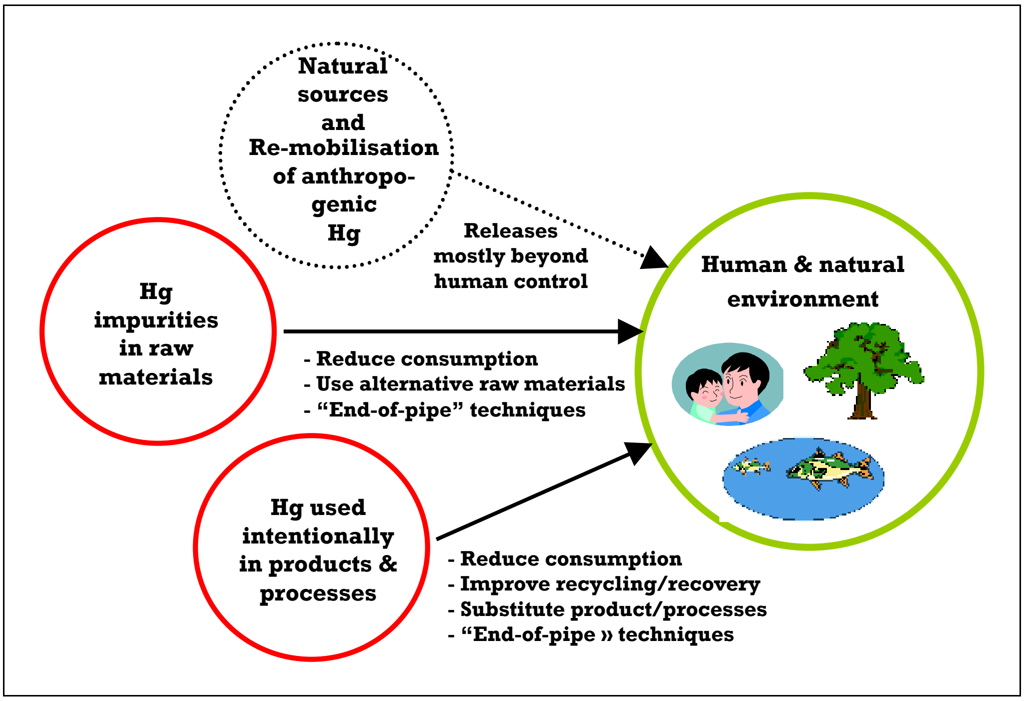

Figure 8.1 Key sources of mercury releases to the environment, and main control options.

603. Releases due to natural mobilisation of mercury and re-mobilisation of anthropogenic mercury previously deposited in soils, sediments and water bodies are not well understood and are largely beyond human control. The other two categories are current anthropogenic mercury releases. Reducing or eliminating these releases may require:

- Investments in controlling releases from and substituting the use of mercury-contaminated raw materials and feedstocks, the main source of mercury releases from unintentional uses; and
- Reducing or eliminating the use of mercury in products and processes, the main source of releases caused by the "intentional" use of mercury.

604. The specific methods for controlling mercury releases from these sources vary widely, depending upon local circumstances, but fall generally under the following four groups:

A. Reducing mercury mining and consumption of raw materials and products that generate mercury releases;
B. Substitution (or elimination) of products, processes and practices containing or using mercury with non-mercury alternatives;
C. Controlling mercury releases through end-of-pipe techniques;
D. Mercury waste management.

605. The first two of these are "preventive" measures – preventing some uses or releases of mercury from occurring at all.[17] The latter two are "control" measures, which reduce (or delay) some releases from reaching the environment. Within these very general groupings are a large number of specific techniques and strategies for reducing mercury releases and exposures. Whether or not they are applied in different countries depends upon government and local priorities, information and education about possible risks, the legal framework, enforcement, implementation costs, perceived benefits and other factors.

A. Reducing consumption of raw materials and products that generate mercury releases

606. Reducing consumption of raw materials and products that generate mercury releases is a preventive measure that is most often targeted at mercury containing products and processes, but may also result from improved efficiencies in the use of raw materials or in the use of fuels for power generation. This group of measures could potentially include the choice of an alternative raw material such as using natural gas for power generation instead of coal, or possibly by using a coal type with special constituents (such as more chlorine) because the mercury emissions from burning this type of coal might be easier to control than other coal types.

607. Another possible approach in some regions might be the use of coal with a lower trace mercury content (mercury concentrations appear to vary considerably in some regions depending on the origin of the raw materials). However, there are some limitations and potential problems with this approach. For example, in the case of the utility preference for low-sulfur crude oil, it is likely that some utilities might be willing to pay more for low-mercury coal, which effectively lowers the market value of all high-mercury coal, which in turn might lead to higher consumption of high-mercury coal in regions where utilities have less rigorous emissions controls. Moreover, data collected recently in the US indicate that coal supplies in the US do not vary significantly in mercury content.

608. Nonetheless, such preventive measures aimed at reducing mercury emissions are generally cost-effective, except in cases where an alternative raw material is significantly more expensive or where other problems limit this approach.

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[17] "Pollution prevention" refers to any practice which reduces the amount of a pollutant entering the waste stream or otherwise released to the environment prior to recycling, treatment, or disposal. It can include a wide range of activities, such as toxics use reduction, material substitution, process or equipment modification, and better management practices.

B. Substitution of products and processes containing or using mercury

609. Substitution of products and processes containing or using mercury with products and processes without mercury may be one of the most powerful preventive measures for influencing the entire flow of mercury through the economy and environment. It may substantially reduce mercury in households (and reduce accidental releases, as from a broken thermometer), the environment, the waste stream, incinerator emissions and landfills. Substitutions are mostly cost-effective, especially as they are demanded by a larger and larger market. This group of measures would also include the conversion of a fossil-fueled generating plant to a non-fossil technology.

610. At the same time, it would be a mistake to assume that substitution is always a clear winner. For example, in the case of energy-efficient fluorescent lamps, as long as there are no competitive substitutes that do not contain mercury, it is generally preferable from a product-life-cycle perspective to use a mercury-containing energy-efficient lamp rather than to use a less efficient standard incandescent lamp containing no mercury, as a result of current electricity production practises.[18]

C. Controlling mercury emissions through end-of-pipe techniques

611. Controlling mercury emissions through end-of-pipe techniques, such as exhaust gas filtering, may be especially appropriate to raw materials with trace mercury contamination, including fossil-fueled power plants, cement production (in which the lime raw material often contains trace mercury), the extraction and processing of primary raw materials such as iron and steel, ferromanganese, zinc, gold and other non-ferrous metals and the processing of secondary raw materials such as iron and steel scrap. Existing control technologies that reduce SO_2, NO_x and PM for coal-fired boilers and incinerators, while not yet widely used in many countries, also yield some level of mercury control. For coal-fired boilers, reductions range from 0 to 96 percent, depending on coal type, boiler design, and emission control equipment. On average, the lower the coal rank, the lower the mercury reductions; however, reductions may also vary within a given coal rank. Technology for additional mercury control is under development and demonstration, but is not commercially deployed. In the long run, integrated control strategies that target multiple pollutants including SO_2, NO_x, PM and mercury may be a cost-effective approach. However, end-of-pipe control technologies, while mitigating the problem of atmospheric mercury pollution, still result in mercury wastes that are potential sources of future emissions and must be disposed of or reused in an environmentally acceptable manner.

D. Mercury waste management

612. Mercury wastes, including those residues recovered by end-of-pipe technologies, constitute a special category of mercury releases, with the potential to affect populations far from the initial source of the mercury. Mercury waste management, the fourth “control” measure mentioned above, may consist of rendering inert the mercury content of waste, followed by controlled landfill, or it may not treat the waste prior to landfill. In Sweden, the only acceptable disposal of mercury waste now consists of “final storage” of the treated waste deep underground, although some technical aspects of this method are yet to be finalised (see further discussion below).

613. Mercury waste management has become more complex as more mercury is collected from a greater variety of sources, including gas filtering products, sludges from the chlor-alkali industry, ashes,

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[18] An ordinary (incandescent) lamp consumes several times more energy for the same lumen output as a fluorescent lamp, and hence results in greater emissions of mercury, assuming most of the energy is produced with fossil fuels. According to the International Association for Energy-Efficient Lighting (IAEEL) Newsletter No. 3 (1993), and Newsletter No’s 1 and 4 (1994), the extra energy consumed by an incandescent lamp results in 2.6 times more mercury than an average compact fluorescent lamp with the same light intensity, and up to 12 times more mercury than a low-mercury fluorescent lamp, even assuming all of the mercury in the fluorescent lamp is eventually released. (As noted in the text, the mercury content of fluorescent lamps varies widely.) These figures are based on the American energy mix for production of electricity, comprising 56 percent coal, 9 percent fossil gas, 4 percent oil and 31 percent non-fossil fuels. The European energy mix is similar, but diverges significantly for certain countries such as Norway and Sweden that are much more dependent on hydropower. Recycling energy-efficient lamps further reduces their environmental impact.

slags, and inert mineral residues, as well as used fluorescent tubes, batteries and other products that are often not recycled. Low concentrations of mercury in waste are generally permitted in normal landfills, while some nations only allow waste with higher mercury concentrations to be deposited in landfills that are designed with enhanced release control technologies to limit mercury leaching and evaporation. The cost of acceptable disposal of mercury waste in some countries is such that many producers now investigate whether alternatives exist in which they would not have to produce and deal with mercury waste. Mercury waste management, as it is most commonly done today, in accordance with national and local regulations, increasingly requires long-term oversight and investment. Proper management of mercury wastes is important to reduce releases to the environment, such as those that occur due to spills (i.e. from broken thermometers and manometers) or releases that occur over time due to leakage from certain uses (e.g., auto switches,[19] dental amalgams). In addition, given that there is a market demand for mercury, collection of mercury-containing products for recycling limits the need for new mercury mining.

Emission prevention and control measures

614. As illustrated in Figure 8.1, a well thought-out combination of emission prevention and control measures is an effective way to achieve optimal reduction of mercury releases. If one considers some of the more important sources of anthropogenic mercury releases described in previous chapters, one may see how prevention and control measures might be combined and applied to these sources:

- Mercury emissions from **municipal and medical waste incinerators** may be reduced by separating the small fraction of mercury containing waste before it is combusted. For example, in the USA, free household mercury waste collections have been very successful in turning up significant quantities of mercury-containing products and even jars of elemental mercury. Also, separation programmes have proved successful in the hospital sector and a number of hospitals have pledged to avoid purchasing mercury-containing products through joint industry-NGO-Government programmes. However, separation programmes are sometimes difficult or costly to implement widely, especially when dealing with the general public. In such cases a better long-term solution may be to strongly encourage the substitution of non-mercury products for those containing mercury. As a medium term solution, separation programs may be pursued, and mercury removed from the combustion stack gases. Mercury emissions from medical and municipal waste incineration can be controlled relatively well by addition of a carbon sorbent to existing PM and SO_2 control equipment, however, control is not 100% effective and mercury-containing wastes are generated from the process;
- Mercury emissions from **utility and non-utility boilers**, especially those burning coal, may be effectively addressed through pre-combustion coal cleaning, reducing the quantities of coal consumed through increased energy efficiency, end-of-pipe measures such as stack gas cleaning and/or switching to non-coal fuel sources, if possible. Another potential approach might be the use of coal with a lower mercury content. Coal cleaning and other pre-treatment options can certainly be used for reducing mercury emissions when they are viable and cost-effective. Also, additional mercury capture may be achieved by the introduction of a sorbent prior to existing SO_2 and PM control technologies. These technologies are under development and demonstration, but are not yet commercially deployed. Also, by-products of these processes are potential sources of future emissions and must be disposed of or reused in an environmentally acceptable manner;

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[19] At secondary steel mills in the USA where end-of-life automobiles and appliances are processed, the predominant source of mercury is believed to be the components in the automobiles/appliances, not natural impurities. The mercury components of greatest concern are switches. Therefore, either emissions control technologies or effective switch removal/collection programs are necessary to minimize mercury releases. For reference material on this topic, see New Jersey DEP’s December 2001 Mercury Task Force Report, and Maine DEP's Plan to Reduce Mercury Releases from Motor Vehicles in Maine, January 2002, available on their websites. It should be noted that some of Europe's secondary steel mills may differ in this regard from other regions due to restrictions on the sale of new cars with mercury switches which became effective in 1993 in Sweden and was followed by automobile manufacturers in other parts of Europe.

- Mercury emissions due to **trace contamination of raw materials or feedstocks** such as in the cement, mining and metallurgical industries may be reduced by end-of-pipe controls, and sometimes by selecting a raw material or feedstock with lower trace contamination, if possible.
- Mercury emissions during **scrap steel production**, scrap yards, shredders and secondary steel production, result primarily from convenience light and anti-lock brake system (ABS) switches in motor vehicles; therefore a solution may include effective switch removal/collection programmes;
- Mercury releases and health hazards from **artisanal gold mining** activities may be reduced by educating the miners and their families about hazards, by promoting certain techniques that are safer and that use less or no mercury and, where feasible, by putting in place facilities where the miners can take concentrated ores for the final refining process. Some countries have tried banning the use of mercury by artisanal miners, which may serve to encourage their use of central processing facilities, for example, but enforcement of such a ban can be difficult;
- Mercury releases and occupational exposures during **chlor-alkali production** may be substantially reduced through strict mercury accounting procedures, "good housekeeping" measures to keep mercury from being dispersed, properly filtering exhaust air from the facility and careful handling and proper disposal of mercury wastes. There are a number of specific prevention methods to reduce mercury emissions to the atmosphere. The US chlor-alkali industry invented the use of ultraviolet lights to reveal mercury vapour leaks from production equipment, so that they could be plugged. Equipment is allowed to cool before it is opened, reducing mercury emissions to the atmosphere. A continuous mercury vapour analyser can be employed to detect mercury vapour leaks and to alert workers so that they can take remedial measures. The generally accepted long-term solution is to encourage the orderly phase-out of chlor-alkali production processes that require mercury, and their substitution with technologies that are mercury free;
- Mercury releases and exposures related to mercury-containing **paints, soaps, various switch applications, thermostats, thermometers, manometers, and barometers**, as well as **contact lens solutions, pharmaceuticals and cosmetics** may be reduced by substituting these products with non-mercury products;
- Mercury releases from **dental practices** may be reduced by preparing mercury amalgams more efficiently, by substituting other materials for mercury amalgams, and by installing appropriate traps in the wastewater system;
- Mercury emissions from dental amalgams during **cremation** may only be reduced by removing the amalgams before cremation, which is not a common practice, or by filtering the gaseous emissions when the practice takes place in a crematorium. Since a flue gas cleaner is an expensive control technique for a crematorium, there might be a strong argument for prevention by substituting other materials for mercury amalgams during normal dental care;
- In cases of **uncontrolled disposal of mercury containing products or wastes**, possible reductions in releases from such practises might be obtained by making these practices illegal and adequately enforcing the law, by enhancing access to hazardous waste facilities, and, over the longer term, by reducing the quantities of mercury involved through a range of measures encouraging the substitution of non-mercury products and processes.

615. When one considers the broad range of restrictions and controls increasingly applied to mercury products and processes as summarized in table 8.1 below and the large (and increasing) resources required to adequately monitor and enforce these measures, one better understands a statement by the Japanese Ministry of Environment (JME, 1997), looking back on the Minamata disaster, and Japan's difficulty in recovering from that experience:

> *"From the purely economic standpoint, too, a large amount of cost and a great deal of time are required to deal with such damages, and, when we compare these costs incurred vs. the cost of the measures that could have prevented the pollution, allowing such pollution is certainly not an economically advisable option."*

Table 8.1. Possible restrictions and controls on mercury (adapted from the submission from the Nordic Council of Ministers, sub84gov)

Mercury production, use and control restrictions in place in various countries

- Prevent or limit the intentional use of mercury in processes
- Prevent or limit mercury from industrial processes (such as chlor-alkali and metallurgic industry) from being released directly to the environment
- Apply emission control technologies to limit emissions of mercury from combustion of fossil fuels and processing of mineral materials
- Prevent or limit the release of mercury from processes to the wastewater treatment system
- Prevent or limit use of obsolete technology and/or require use of best available technology to reduce or prevent mercury releases
- Prevent or limit products containing mercury from being marketed nationally
- Prevent products containing mercury from being exported
- Prevent or limit the use of already purchased mercury and mercury-containing products
- Limit the allowable content of mercury present as impurities in high-volume materials (packaging, etc)
- Limit the allowable content of mercury in commercial foodstuffs, particularly fish, and provide guidance (based on same or other limits values) regarding consumption of contaminated fish

Mercury disposal restrictions in place in various countries

- Prevent mercury in products and process waste from being released directly to the environment, by efficient waste collection
- Prevent mercury in products and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment
- Prevent or limit mercury releases to the environment from treatment of household waste, hazardous waste and medical waste by emission control technologies
- Set limit values for the allowable mercury content in sewage sludge spread on agricultural land
- Restrict the use of solid incineration residues in road-building, construction and other applications
- Prevent the re-marketing of used, recycled mercury

Mercury control options under consideration

- Prevent or limit the dedicated mining of virgin mercury from the Earth's crust
- Prevent or limit the marketing of mercury recovered as a by-product from other mineral or fossil fuel extraction (such as non-ferrous mining activities and natural gas cleaning)
- Control trade of pure mercury in order to restrict it to pre-defined essential uses and secure environmentally safe handling (similar to procedures for hazardous waste)
- Limit the allowable content of mercury present as impurities in fuels and other bulk mineral materials

8.2 Substitution

616. As described in chapter 6, the deliberate use of mercury in products and processes comprises a significant contribution to the mobilisation and release of mercury to the environment. As the general awareness of mercury's adverse effects on human health and the environment has increased, a number of countries have made special efforts to address mercury in these applications, and have had particular success in reducing mercury use. Canada, Denmark, Norway, Sweden and the USA, among others, have seen the number of applications as well as the quantities of mercury used per application decrease significantly, particularly during the last 15-20 years. Nevertheless, since many mercury-containing products have long technical lives, it should be kept in mind that even if a country decides to ban the marketing and use of mercury in most products, it may take decades before most of the mercury in use is collected and removed from human circulation.

617. Today, alternatives are commercially available for virtually all applications of mercury, permitting a near-total phase-out of mercury use in countries that pursue such an objective. However, the Swedish and Danish experiences demonstrate that the public authorities must have a firm commitment and a clear strategy in place. During the implementation of the Swedish ban on mercury in products (except those few products with an exemption), an investigation of substitutes for mercury-containing measuring instruments and electrical components was carried out. It was discovered that while several applications of mercury were being phased out, some new applications, surprisingly, were appearing - as in electronic equipment - even though alternative technologies were available. It was determined that users of mercury-containing products are faced with four main obstacles to the use of viable alternatives. These include:

- The need for developing and testing efforts, e.g. required for security reasons;
- Higher costs and competition;
- Attitudes to, and knowledge of, alternative techniques – even among equipment suppliers;
- Internationally standardised measurements.

618. These are not insurmountable obstacles, but they may require an appropriate programme of information and incentives. A summary of common mercury products and substitutes is provided in table 8.2 below. Because it is only representative of the great range of mercury applications, this table does not attempt to include all mercury applications or all substitutes. Further information may be found in the references, especially the submission from the Nordic Council of Ministers (sub84gov).

Table 8.2 Summary of alternatives to principle mercury uses, with some indications of relative cost (see notes below table).

Product or application	**Alternative(s)**	**General cost relative to mercury technology**
Use of the mercury cell process for producing chlorine, alkali, sodium hydroxide, potassium hydroxide, commonly referred to as chlor-alkali	Best Available Technology (BAT) for the production of chlor-alkali is considered to be membrane technology. Non-asbestos diaphragm technology can also be considered as BAT.	⬜🟧🟥 Capital investment costs for conversion to the other processes are significant, but electricity and raw material costs (together comprising about half of total operating costs) for the membrane process, as well as waste treatment and disposal costs, are lower than for the mercury cell process. EIPPCB (2000)¨, US EPA (1993), Submission from the Nordic Council of Ministers, Lindley (1997)
Dental amalgam	As a result of technological advances in recent years, various newer alternatives (cold silver, gallium, ceramic, porcelain, polymers, composites, glass ionomers, etc.) to mercury amalgam fillings are commercially available. However, the Danish National Board of Health does not deem the alternatives fully capable of substituting mercury amalgam in all cases (e.g. fillings in adult molars), and this is also the current Swedish position. Even the viable alternatives are not yet widely known or accepted in many countries, as practitioners generally find it easier to continue using the techniques with which they are most familiar.	🟩🟧⬜ Some alternatives are less expensive and some are more expensive than mercury amalgams, some are as easy to apply and others are more difficult, but none of the alternatives require the specialized wastewater treatment equipment that dental professionals need to meet environmental regulations in many countries. KEMI (1998), Submission from the Nordic Council of Ministers, Gustafsson (2001), US EPA (1997)
Mercuric-oxide and mercury-zinc (medical) "button cell" batteries	Virtually mercury-free zinc-air batteries and other button-cell alternatives (actually still containing less than 10 mg of mercury) have been available for several years. Many manufacturers no longer produce mercuric-oxide and mercury-zinc batteries, but they remain a significant problem in the municipal waste stream of most countries.	⬜🟧🟥 The cost of alternatives may often be higher than the mercuric-oxide and mercury-zinc batteries, but municipalities can avoid expensive collection and disposal schemes.

Product or application	Alternative(s)	General cost relative to mercury technology
Other batteries	Virtually all other batteries are now available in standard and rechargeable mercury- and cadmium-free versions. Only the older battery manufacturing facilities may continue to produce batteries using the previous techniques and materials.	⬜🟧⬜ While comparisons are difficult across a broad range of batteries (and as battery capacities increase), standard mercury-free batteries generally cost about the same as the batteries they replace. Rechargeable batteries, on the other hand, especially the cadmium-free rechargeables, are significantly more expensive to purchase, although they become relatively less expensive if recharged more than 10 or 15 times.
Medical thermometers	There are many alternatives to clinical mercury-thermometers, including electrical and electronic thermometers, “disposables” designed for a single use, glass thermometers containing a Ga/In/Sn “alloy”, etc.	⬜⬜🟥 Used mostly for measuring body temperature, electronic thermometers have become standard in Denmark and other countries. While they remain somewhat more expensive than glass mercury thermometers, their price has come down substantially in recent years. Other alternatives are also more expensive, although the recently introduced Ga/In/Sn thermometer should approach the cost of old mercury thermometers over time.
Other thermometers	Non-medical thermometers are used very widely. Alternatives to mercury as the measuring medium include other liquids, gas, electrical and electronic (probably the most common) sensors. The choice of alternative depends on the temperature range, the specific application, and the need for precision. (Mercury thermometers are worthless at temperatures below –39°C, when mercury turns solid) For temperature readings in buildings, a bimetal device is often used, or a Pt-100 or thermocouple is used when a temperature signal needs to be transferred to a controller or recorder. Electronic alternatives have several advantages over mercury. One thermometer can be adjusted to several different measuring ranges, thereby substituting for several mercury thermometers. Further, it is possible to read temperatures digitally and record them remotely. This could reduce the chance of human error, as well as reduce operating costs. For a very small number of precision applications, mercury thermometers are still preferred for technical reasons, e.g. for calibration of other thermometer types, for international standards, etc..	⬜🟧⬜ There is such a great range of mercury alternatives and applications that it can only be said that prices of alternatives vary widely, but are not necessarily more expensive. It should also be noted that, while the initial cost of a mercury glass thermometer is lower than an electronic device, the frequency of broken mercury thermometers is higher, and one electronic thermometer may replace several mercury ones. If an annual cost is calculated, the price of an electronic measuring device is probably no higher than the mercury device it replaces. Gustafsson (1997), Submission from the Nordic Council of Ministers, Rasmussen (1992)
Laboratory use of mercury	It is entirely possible to restrict mercury use in school or university laboratories to a few specific, controllable uses (mainly references and standard reagents).	⬜🟧⬜ This initiative has already been implemented in Swedish and Danish legislation. The alternatives are generally no more expensive, and the need for control of mercury sources in the laboratory is greatly reduced.
Pesticides and biocides for different products and processes.	The use of mercury in pesticides and biocides has been discontinued or banned in many countries. Two main alternatives have been promoted in their place: 1) Use of processes not requiring chemical pesticides/biocides, and 2) Easily degradable, narrow-targeted substances with minimal environmental impact.	⬜🟧⬜ These alternatives are in place in many countries. The range of products and applications is too diverse to make definitive statements about cost comparisons, although it is likely that in the majority of cases costs are roughly comparable, and environmental benefits are considerable.

<table>
<tr><th>Product or application</th><th>Alternative(s)</th><th>General cost relative to mercury technology</th></tr>
<tr><td>Pressure measuring and control equipment</td><td>Mercury is used as a “heavy liquid” in pressure gauges, pressure switches and pressure transmitters. All of these may be substituted without any loss of accuracy or reliability. Three main technologies are used:
• flexible membranes,
• piezoelectric crystals and other sensors that change some physical property when the pressure changes, and
• fiber-optic pressure sensors, based on light transmission.
In pressure gauges like U-tube meters, barometers, and manometers, mercury is used to continuously indicate pressure differentials. Here, mercury can be replaced by another liquid, by gas or by other techniques.
Mercury pressure switches are used to measure pressure or vacuum differentials. They can be replaced by the same alternatives as for pressure gauges, but also equipped with a non-mercury breaker switch.
For remote transmission of measurement readings, a pressure transmitter is often used. A special mercury transmitter is a circular tube which may contain up to 8 kg of mercury. Alternatives use a potentiometer or a differential transformer to measure pressure changes and transmit an electronic signal. The most common alternative device is a diaphragm sensor.</td><td>☐🟧☐
Alternatives based on gas, other liquids or a mechanical spring show no significant differences in price, compared to mercury devices. Alternatives in the form of electric and electronic instruments are only slightly more expensive, but have several advantages over mercury.
Gustafsson (2001), Rasmussen (1992), Submission from the Nordic Council of Ministers.</td></tr>
<tr><td>Electrical and electronic components</td><td>With very few exceptions, there are no technical obstacles to replacing electrical components, conventional relays and other contacts (even when these are contained in level switches, pressure switches, thermostats, etc.) with equivalent mercury-free components. A number of examples are given below.</td><td rowspan="2">☐🟧☐
There are no significant price differences between conventional mercury and mercury-free relays and contacts, except for very specific applications. There are also examples of mercury components, which are more expensive than the alternatives.
Gustafsson (1997).</td></tr>
<tr><td colspan="2"><table>
<tr><td>Mercury component</td><td>Alternative component</td><td>Application</td></tr>
<tr><td>Tilt-switch – silent switch</td><td>Various, e.g. manual/mechanical (rolling steel ball, alternative conducting fluid), micro-switch</td><td>Circuit control, thermostats, communications</td></tr>
<tr><td>Electronic-switch</td><td>Solid state-switch, optical switch</td><td>Circuit control, thermostats, communications</td></tr>
<tr><td>Reed-switch – “mercury-wetted”</td><td>Solid-state-switch, electro-optical-switch, semi-conductor</td><td>Communications, circuit control in sensitive electronic devices</td></tr>
<tr><td>Proximity sensor/switch – “non-touch-contact”</td><td>inductive sensor
capacitive sensor
photoelectric sensor
ultrasonic</td><td>shaft rotation, conveyors
conveyors
conveyors
conveyors</td></tr>
</table></td></tr>
</table>

Product or application	Alternative(s)	General cost relative to mercury technology
Energy-efficient lamps	Currently, there are no mercury-free energy-efficient alternatives to the energy-efficient lamps on the market, although there are reports of a high-efficiency non-mercury lamp based on the field-emission effect, which is said to be starting production in China[20], and a lamp based on diode technology is in research. One can only prescribe production/use of energy-efficient lamps with a minimum mercury-content, and collection and treatment of spent lamps. According to European Commission Decision 1999/568/EC (amended 9 September 2002), for a manufacturer to be allowed to use the European Ecolabel on a single-ended compact fluorescent lamp, the mercury content must not exceed 4 mg, and the life of the lamp must exceed 10,000 hours. Other mercury-containing light sources exist, mainly for special, limited purposes and sold in much lower quantities, although recently introduced and fashionable auto headlamps containing mercury are a particular concern, as they are inconvenient to recover and recycle, and perfectly acceptable non-mercury alternatives are available.	🟩🟧⬜ Low-mercury lamps are slightly more expensive than those with a bit more mercury. Incandescent and some other alternative lamps are less expensive than energy-efficient lamps, but they have a much higher energy/operating cost. Falk (1994), Gustafsson (1997), Submission from the Nordic Council of Ministers.
Artisanal gold extraction	One alternative that seems to offer promise is a non-mercury electrolytic process (see section 8.5.3) started in Brazil. However, it has been in existence for some 10 years and does not seem to have convinced the artisanal community. An alternative is a cyanidation process, which is reportedly used by many relatively small-scale miners in Mexico and some elsewhere, despite the fact that it requires greater investments and greater process skills, and carries its own hazards. Another option is the Minataur process developed in South Africa by the government's mineral technology research body, Mintek. This involves treating the ore with hydrochloric acid in the presence of sodium hypochlorite and then using sodium metabisulphate or oxalic acid to precipitate the gold out as a concentrate that is 99.5% fine gold powder. UNIDO's approach in addressing this problem is to encourage the substitution of low recovery, high mercury consuming and discharging processes with environmentally safe and high-yield gold extraction alternatives that sharply reduce or eliminate the use and discharge of mercury. Depending upon the technique, cost and delivery method, some proposals are better received than others, but none as yet have been widely adopted. A typical technique, developed by Imperial College Consultants (ICON), London, uses substantially less mercury and has demonstrated a 40-50 % better gold recovery efficiency.	⬜🟧⬜ The economics of these alternatives have not been investigated in detail here, but indications (the first process used on a wide scale, and the second delivering more gold and using less mercury) are that they are no more expensive than the traditional mercury process. If they were, they would not be adopted by the garimpeiros. CETEM/IMAAC/CYTED (2001), ICON (2000), UNIDO (1997), UNIDO (2000), MMSD (2002)

Note: The coloured bar is an indicator of the overall user/consumer price level for mercury-free alternatives as compared to mercury technology. Price-determining factors vary among the uses (expenses for purchase, use, maintenance etc.), but do not include external costs.

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Green (left) = lower cost alternative,
Orange (centre) = similar cost
Red (right) = higher cost.

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[20] See http://www.lightlab.se/english/products/index.htm.

8.2.1 Denmark's experience

619. A good example of the potential achievements of a coherent substitution strategy is evident from the experience of Denmark. In recent years Denmark decided to strongly encourage substitutes for mercury products, including placing a ban on the sale and use of most mercury products. As in a number of other countries, a substantial decrease in mercury consumption for intentional uses has been observed. As can be seen in table 8.3, during the period 1983-1993 the annual consumption of mercury in intentional uses fell from about 16 metric tons in 1982/83 to 6 metric tons in 1992/93, and decreased further to 1.5 metric tons in 2000/2001. In the same period, releases to the environment were reduced from an estimated 6.9-9.9 metric tons in 1983, to 2.3-3.0 tons in 1993 (of which 0.3-0.8 tons originated from trace amounts of mercury in fuels and minerals). The deposits in (controlled) landfills have increased during the same period from 1.7-2.9 metric tons to 2.3-4.5 tons, most likely as a result of increased hazardous waste collection (reflecting the mercury content of used products, batteries, etc.) and improved filtering of waste incinerator emissions.

Table 8.3 Estimated changes in annual consumption of mercury in Denmark (metric tons/year). Ref. Submission from the Nordic Council of Ministers (sub84gov), based on Maag et al. *(1996), Hansen (1985) and Heron (2001).*

Danish national consumption of mercury	**Year/use**	**1982/83**	**1992/93**	**2000/2001**
	Chlor-alkali production (discontinued in 1997)	3.00	2.50	0
	Dental amalgam	3.1	1.80	0.9
	Mercury-oxide batteries	2.40	0.36	0
	Other batteries	2.30	0.28	~ 0
	Measuring and control equipment	0.53	0.50	0.3
	Electric and electronic switches	0.34	0.30	~ 0
	Light sources (lamps)	0.14	0.17	0.17
	Medical thermometers	0.75	0.05	0
	Other thermometers	1.55	0.10	0
	Laboratory chemicals	0.50	0.09	0.09
	Other intentional uses	1.48	0.03	0.03
	Sub-total, intentional uses	16.09	6.18	1.5
	Impurities in consumed fuels, minerals and high-volume materials (non-intentional mobilisation)	1.96	1.80	1.8
	Total	18.05	7.98	3.3

Note: Shading indicates graphically the approx. change in quantities of mercury consumed over time.

8.2.2 Need for further development of substitutes

620. For a very few applications, representing a relatively small amount of mercury consumption, more research and development is needed in order to be able to completely eliminate mercury use (submission from the Nordic Council of Ministers, sub84gov).

Fluorescent lamps

621. For mercury use in fluorescent lamps, which are known for their low energy consumption, no commercially mature alternatives are yet available. Work has been done, however, to reduce the amount of mercury needed in each lamp. From typical amounts of 20-40 mg of mercury per lamp, lamps with only 3 mg of mercury are commercially available today. Unfortunately these modern low-mercury lamps have difficulty in competing on price with the higher-mercury lamps, and consumers are generally unaware of the difference between them.

622. The use of diodes as lights – recently installed in some traffic lights - has been proposed as an energy-efficient substitute. The strength of the light source for this application would appear to be comparable to what is needed for some housing purposes. However, until mercury-free alternatives are widely deployed, the mercury in fluorescent lamps may be managed by collection of used lamps and recycling or proper waste treatment. This has been attempted in a few countries and localities, but it has been difficult in most cases to achieve significant collection rates.

Dental amalgam

623. As mentioned in chapter 6, mercury amalgam fillings contribute significantly to the human (metallic) mercury burden. While there has been substantial developmental work on a range of alternatives, there is not yet a consensus that substitutes can adequately replace mercury amalgams in all dental applications. In Sweden and Denmark voluntary substitution agreements have been in place for a number of years and the consumption of mercury for dental use has decreased significantly. In Denmark mercury amalgams are permitted (until further notice) only in molars where the fillings are worn.

Chemical standard analyses

624. A number of traditionally important chemical standard analyses involve the use of mercury compounds. While mercury-free substitutes are generally available, this issue is mentioned here because it may take time to change standards previously agreed upon. For example, a common analysis using mercury is the COD (chemical oxygen demand - measuring contents of organic matter) analysis, which is widely used to control and monitor the quality of wastewater. Other oxygen demand (e.g., the so-called BOD – biological oxygen demand) analyses are available and are often used. However, the problem is that the prescriptions of many mandatory analyses in regulations and individual wastewater release permits specify the COD analysis, and need to be changed. This is possible, but requires attention and time. The Swedish government is considering a ban on mercury use in chemicals for analyses and reagents from 1 January 2004.

8.3 Reducing mercury releases

625. Processing of mineral resources at high temperatures, such as combustion of fossil fuels, roasting and smelting of ores, kiln operations in the cement industry, as well as incineration of wastes and production of certain chemicals, results in the release of a number of volatile trace elements into the atmosphere.

626. It is often believed that a combustion unit – typically used for power generation or waste incineration – with an emission control device removes most or all of the mercury and other heavy metals emitted during combustion. However, unlike other heavy metals, mercury has special properties as described in chapter 6, that make it difficult to capture in many control devices. While some units with control devices do remove mercury quite effectively,[21] there are likely tens of thousands of combustion units around the world with no flue gas cleaning devices at all, or where such devices are not effective in removing mercury.

627. While this section is focused on mercury emissions to the atmosphere, it should be remembered that mercury is a persistent pollutant that also cycles through other environmental media (e.g., water and soil). Further, it should be kept in mind that mercury that is captured in a pollution control device or diverted from an incinerator may still be released to the environment unless the slags or residues are properly managed.

628. Significant parts of the descriptive text in sections 8.3.1 through 8.3.4 below have been based on Pacyna and Pacyna (2000).

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[21] Based on data gathered by US EPA in 1999 on mercury emissions from electric utilities, control device efficiencies, and other information, mercury emission reductions effected by current controls for other pollutants ranged from 0 to over 90 percent. In the USA, many waste incineration units with control devices are achieving even higher levels of mercury control.

8.3.1 Nature of mercury emissions

629. In order to fully appreciate the relevance of various emission control technologies, it is first necessary to review the context of these mercury emissions (Pacyna and Pacyna, 2000, as modified by US comments to an earlier draft of this report).

- Concentrations of mercury in coals and fuel oils vary substantially depending on the type of fuel and its origin. The mercury in coal may be associated with the organic or the inorganic constituents (mineral matter) of coal. When it is associated with mineral matter such as sulfides it can often be removed by physical coal cleaning techniques. The removal of mercury from the organic fraction of coal is much more difficult and costly.
- Most of the processes generating atmospheric emissions of mercury employ high temperature. During these processes, including combustion of fossil fuels, incineration of wastes, roasting and smelting operations in non-ferrous and ferrous metallurgy, and cement production, mercury introduced with input material volatilizes and is converted to elemental mercury (Hg^0) in the high temperature region of the process. As the flue gas is cooled to flue gas cleaning temperatures the mercury may remain as Hg^0 or part of it may be oxidized to ionic mercury [Hg(II)]. Further, Hg^0 and/or Hg(II) may be adsorbed onto particles to form particle-bound mercury [Hg(p)]. The relative magnitude of Hg^0, Hg(II), and Hg(p) in flue gas is called the speciation of mercury.
- Mercury oxidization can result from gas-phase or gas-solid reactions (heterogeneous reactions). Laboratory experiments and thermal-chemical studies have implicated atomic chlorine (Cl^-) and nitrogen oxide (NO_2) as two potential oxidizing agents. Thermal-chemical equilibrium studies indicate that the preferred oxidation product is $HgCl_2$ when sufficient chlorine is present in the fuel or waste (i.e., when the concentration of chlorine is substantially higher than the concentration of mercury in the flue gas). Fly ash and other surfaces within the combustion system can catalyze or mediate mercury oxidization reactions. Major factors that affect mercury speciation are the fuel (or waste) composition, the combustion conditions, and the type of flue gas cleaning methods used.
- Various technologies within the same industry may generate different amounts of atmospheric emissions of mercury. It can be generalized for conventional thermal power plants that the plant design, particularly the burner configuration, fly ash characteristics, etc., have an impact on the emissions.[22]
- The major parameters that determine the amount and characteristics of mercury emitted to the atmosphere from high-temperature processes are the amount and speciation of mercury entering the flue gas cleaning devices, the type of flue gas cleaning devices used, the concentrations of other constituents (chlorine, NO_x), and the temperature at which the flue gas cleaning devices are operated.

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[22] Cyclone- and pulverized coal- (PC) fired boilers both operate at temperatures that volatilise the mercury in coal and convert it to Hg^0 in the high-temperature regions of the furnace. The difference in stack emissions of mercury from these two types of units is probably due to the amount and characteristics of fly ash. In cyclone-fired units most of the mineral matter is converted to slag, which is removed in a molten form in the bottom of the combustion unit. A relatively small amount of the mineral matter is converted to fly ash, which in turn contains a relatively small amount of unburned carbon. In PC-fired boilers, approximately 90 percent of the coal mineral matter is converted to fly ash. The use of low- NO_x burners tends to increase the amount of carbon in fly ash, increasing the amount of mercury that is adsorbed and subsequently captured as Hg(p) in a downstream electrostatic precipitator (ESP) or fabric filter (FF).

A similar phenomenon has been observed in systems that burn municipal solid waste. Some mass-burn-water-wall incinerators exhibit very good combustion and low fly ash carbon concentrations. Well operated mass-burn units equipped with spray dryer and fabric filters (SD/FFs) exhibit little if any mercury capture. Alternatively, US tests on one refuse-derived-fuel (RDF) combustor equipped with a SD/FF exhibited mercury captures ranging from 96 to 99 percent. In a similar fashion, fluidized bed incinerators typically emit relatively large amounts of fly ash with a high carbon content. While improved mercury capture by fly ash sometimes correlates with low NO_x emission, there does not appear to be a cause and effect relationship between the flue gas concentration of NO_x and mercury capture.

8.3.2 Available options

630. The options available for reducing mercury releases from various processes may be organized in two categories: non-control-technology options, and control-technology options.

631. The best-known **non-control-technology options** include such measures as:

- Conversion to natural gas, oil, or a non-fossil power generating technology;
- Improved energy efficiency (reductions of CO_2-emissions as foreseen in the Kyoto Protocol to the UN Framework Convention on Climate Change are expected to help reduce mercury emissions from fossil fuel power generation);
- Banning mercury in products;
- Taxes or other disincentives to the use of mercury in products; and
- Product labeling.

632. Banning and taxes are reasonably self-explanatory. Product labelling has advantages and disadvantages, but has proven rather effective in some cases, in combination with other measures. For example, in the case of consumer batteries, consumers paid significant attention to labels concerning the content of mercury and cadmium.

633. **Control-technology options** for reducing releases may be thought of in the following three categories, which are further elaborated in the next section:

A. Pre-treatment measures;
B. Combustion modifications; and
C. Flue gas cleaning or end-of-pipe controls.

634. It should be noted that the descriptions of techniques and technologies for emission reductions that follow are general, and not intended to prescribe methods or equipment that should be used to control mercury releases from any specific site or plant. The ultimate appropriateness and effectiveness of any given technique or technology is site specific, and needs to take into consideration local circumstances.

8.3.3 Reducing mercury emissions from utility and non-utility boilers and incinerators[23]

A. Pre-treatment measures

635. **Pre-treatment** measures typically include coal washing, hand-sorting of waste at an incinerator or disposal site, the production of refuse-derived fuel at an incinerator site, or the separation of waste at a material recycling and handling facility.

B. Combustion modifications

636. **Combustion modifications** act to change the combustion process. These modifications may be used to reduce mercury concentrations in the process flue gas, or they may be used to change the characteristics of the flue gas stream so that mercury is more easily captured in downstream flue gas cleaning equipment. The modifications may include using technologies such as fluidized bed combustor, mass burn/waterwall combustor, low-NO_x burner, etc.

637. As an example, combustion modification-based low-NO_x technologies should reduce mercury emissions in the exhaust gases due to lower operating temperatures, although very limited information on this technology makes it difficult to draw firm conclusions. While some sources indicate that a reasonable reduction can be achieved, other preliminary results of staged combustion in atmospheric fluidized bed combustion (AFBC) units indicated that low-NO_x had little effect on trace element emissions.

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[23] For considerably more detail about recent US developments in this field, the reader is invited to consult US EPA (1998), Brown *et al.* (1999) and US EPA (2002).

638. Switching to the same type of fuel, but with lower mercury content, which does not involve pre-treatment, may also be considered a combustion modification.

639. Other examples of modifications that can potentially be used to improve capture of mercury are combustion modification techniques that increase the carbon content and subsequent mercury adsorption capacity of fly ash. Increased fly ash carbon content occurs during the use of low-NO_x burners or the use of a NO_x control technology called reburning. This results from fuel-rich regions within the combustion system. While increased mercury capture has been shown to occur with increased fly ash carbon, this phenomenon has not been used in commercial practice for the control of mercury emissions, and it should be considered a potential control option that might be available in the future.

C. Flue gas treatment (end-of-pipe) controls

640. **Flue gas treatment, or end-of-pipe, controls** are currently deployed for control of SO_2, NO_x, and PM: SO_2 controls include a variety of wet and dry scrubbers; NO_x may be controlled by selective catalytic or selective non-catalytic reduction; and PM may be controlled by fabric filters (FFs) or electrostatic precipitators (ESPs). There has been extensive testing of the mercury removable capabilities of these systems on a wide range of coal-fired utility boilers in the USA. The average results ranged from 0 to 96 percent dependent on a variety of factors as described in detail below. Generally speaking:

- A specific technology, or combination of technologies, produced a range of mercury reduction for any coal type;
- The type of coal strongly affected the mercury control achieved, with average percent removal increasing as coal "rank" increased from lignite through subbituminous to bituminous. Within any given rank, a range of removals was achieved. Note also that world coals represent a wider range of coal rank (e.g. brown coal) and characteristics (e.g. sulfur, ash) than US coals.

641. Additional mercury control can be achieved by injection of a sorbent (carbon- and/or calcium-based) prior to the flue gas treatment system. These technologies are currently under development and demonstration in the USA, but are not yet commercially deployed.

642. Research so far has indicated that the most cost-effective approach to mercury control may be an integrated multipollutant (SO_2, NO_x, PM, and mercury) control technology. A number of these technologies are in the pilot-scale development stage in the USA, but have generally not yet been demonstrated at full-scale. Recent Swedish experience has demonstrated the economic as well as technical efficiency of such systems in full-scale waste incinerators and utility burners (Hylander *et al.,* 2002, as cited in comments from Uppsala University, Sweden).

643. The potential impact of mercury control technology on by-product utilization and/or disposal needs to be evaluated. For example, increased mercury concentration in the gypsum collected in flue-gas scrubbers may exceed the level permitted in wallboard; or an increased carbon content in the by-product may limit its use in aggregate used for road surfacing. Furthermore, any by-product must be in a stable form for disposal if it cannot be utilized. Either of these potential impacts would affect the cost-effectiveness of the process.

644. The major mercury capture mechanisms include the adsorption of mercury onto solid surfaces and the solvation of mercury in liquid scrubbers. Mercury can be adsorbed onto fly ash or entrained sorbent particles for subsequent capture in particulate matter (PM) control devices. Mercury can also be captured in packed beds containing a variety of sorbents.

645. Distribution of mercury within the various streams of wet flue gas desulfurisation (FGD) systems has been studied in a number of countries. These studies have shown that mercury capture in wet FGD systems depends on the rank of coal burned, and the design and operating conditions of the FGD system. Wet FGD scrubbers were generally preceded by PM control devices (i.e., ESPs or FFs). The total amount of mercury captured in a boiler equipped with a scrubber depended on the amount of mercury captured in the upstream PM control device and the soluble Hg^{2+} captured by the scrubber. Flue

gas from the exhausts of units burning bituminous coals exhibited higher levels of Hg^{2+} than flue gas from burning of lower rank coals; this mercury was readily captured in the PM control device and downstream scrubber. Mercury in the exhausts of units burning low rank coals tended to be Hg^0, and mercury capture in these units tended to be minimal. The scrubber chemistry must also be controlled to insure that Hg^{2+} that is dissolved in the scrubber liquor is not converted back to Hg^0 and re-entrained in the flue gas. Scrubber sludges must also be handled in an environmentally acceptable manner.

646. Pacyna reported that some wet FGD systems are unable to remove more than 30 percent of the mercury in the flue gas, but in general the removal efficiency ranges from 30 to 50 percent (Pacyna and Pacyna, 2000). Short-term tests in the USA have exhibited emission reductions for units firing bituminous coals that range from 40 to 95 percent. The best capture was found for a unit equipped with a FF and a wet limestone (a type of FGD) scrubber.

647. Soluble forms of mercury can be captured in wet scrubbers. Soluble forms of mercury include mercuric chloride [$Hg(Cl_2)$] and other ionic forms of mercury. Hg^0 is relatively insoluble in aqueous solutions and it must either be adsorbed onto a solid, or it must be oxidized to an ionic form that can be captured by scrubbing. Wet FGD systems used on units burning bituminous coal (which emit relatively more of the water soluble ionic mercury) perform much better than do such systems on units burning subbituminous coal (which emit relatively more non-soluble elemental mercury).

648. Major factors that affect mercury speciation are the fuel (or waste) composition, the combustion conditions, and the type of flue gas cleaning methods used. Coal rank and chlorine content are extremely important factors in the speciation and capture of mercury with different types of air pollution control technologies. In the USA, bituminous coals tend to have relatively high concentrations of chlorine (Cl). This can result in the oxidization of Hg^0 to Hg^{2+} (primarily $HgCl_2$). The Hg^{2+} can be adsorbed onto fly ash carbon and captured in an ESP or FF. Bituminous pulverized-coal (PC) fired boilers equipped with an ESP or FF may exhibit total mercury captures ranging from 20 percent to more than 90 percent. The higher levels of capture are believed to be associated with a higher fly ash carbon content. However, carbon in fly ash can negatively impact its use as a by-product in concrete, as well as negatively impact plant heat rate. Units that burn bituminous coal, and that are equipped with dry flue gas desulfurization (FGD) scrubbers or wet FGD scrubbers, also exhibit high levels of mercury capture. In contrast, low rank US coals (subbituminous coal and lignite) are alkaline, have a relatively low chlorine content, and have fly ash with a low carbon content. Mercury in the exhausts of plants burning low rank coals tends to be predominately Hg^0. The capture of mercury from the flue gas from these plants tends to be low, whether the units are equipped with an ESP, FF, dry FGD scrubber, or wet FGD scrubber.

649. Conventional mercury measurement methods must be carefully performed to effectively determine the critical speciation distribution (i.e., Hg^0/Hg^{2+}). In addition, continuous emission monitors (CEMs), intended to provide a direct determination of either total Hg^0 and/or Hg^0 and Hg^{2+} are currently under development and evaluation in the field.

(1) Wet FGD systems

650. Distribution of mercury within various streams of the wet FGD system was studied in a number of countries. The relatively low temperatures found in wet scrubber systems helped many of the more volatile trace elements to condense from the vapour phase and thus to be removed from the flue gases. Due to the special characteristics of mercury, wet FGD facilities are sometimes unable to remove more than 30 percent of the mercury in exhaust gases. In general, however, removal efficiency for mercury ranges from 30 to 50 percent (Pacyna and Pacyna, 2000).

651. Removal of trace elements from exhaust gases by wet FGD systems has been studied in the Netherlands, where only pulverized coal-fired dry-bottom boilers are used, equipped with a high-efficiency electrostatic precipitator (ESP) and an FGD design that consists of a wet lime/limestone-gypsum process with “prescrubber.” Mostly bituminous coals (lower mercury content) imported mainly from the USA and Australia are burnt. In one study the mercury concentration upstream of the

FGD system was 3.4 µg/m^3 and downstream was 1.0 µg/m^3. The relative distribution of mercury among bottom ash, collected pulverised-fuel ash and fly-ash in the flue gases and in the vapour phase was about 10 percent on fine particles and about 90 percent in vapour phase. 87 percent of the mercury content of the coal was released in the flue gases, and up to 70 percent of that was removed by the wet FGD system. About 60 percent of mercury removal takes place in the prescrubber and about 40 percent in the main scrubber. These mercury removal stages are summarized in figure 8.2 below (Pacyna and Pacyna, 2000).

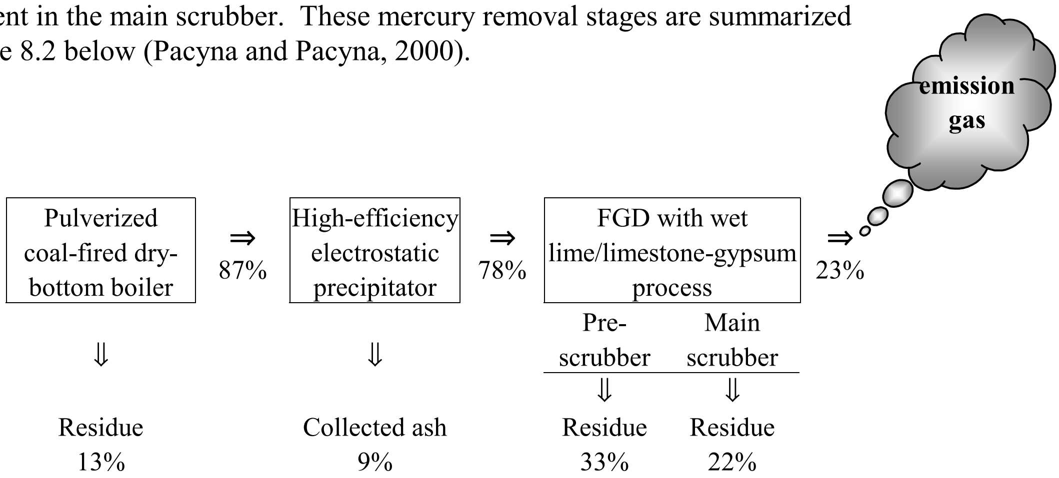

Figure 8.2 Reducing mercury emissions with wet FGD systems

652. Mercury mass balances are difficult to make. They are dependent on equipment configurations and operating conditions used at each individual site. For example, the partitioning of mercury among bottom ash (residue), collected fly ash, scrubber residues, and stack emissions may vary substantially depending on the coal rank, the boiler design, plant operating conditions, and the flue gas cleaning methods used.

(2) Dry FGD systems

653. Retention of vapour phase mercury by spray dryers has been investigated in Scandinavia and the USA for coal combustors and for incinerators. In summary, the overall removal of mercury in various spray dry systems varied from about 35 to 85 percent. The highest removal efficiencies were achieved in spray dry systems fitted with downstream fabric filters (Pacyna and Pacyna, 2000).

(3) Mercury-bearing particle emissions

654. Coal-fired power plants and municipal incinerators are most frequently equipped with either **electrostatic precipitators** (ESPs) or fabric filters. ESPs are particularly efficient in removing all types of particles with diameters larger than 0.01 µm, including those bearing mercury after condensation within exhaust gases. Particles containing trace elements are concentrated mostly in two size ranges: 1) at ca. 0.15 µm diameter and 2) between 2 and 8 µm diameter. Mercury can be found on particles in both size ranges. ESPs can tolerate operating temperatures as high as 720 K (Pacyna and Pacyna, 2000).

655. **Fabric filters** are also used in coal-fired power plants. The particle collection efficiency (not the same as the mercury collection efficiency) is always very high, and even for particles of 0.01 µm diameter, exceeds 99 percent. However, the durability of fabric filters is very dependent upon the working temperature and their resistance to chemical attack by corrosive elements in exhaust gases. The temperature of exhaust gases often exceeds the temperature tolerance for fabric filter material, and therefore limits the application of fabric filters (Pacyna and Pacyna, 2000). According to comments from the US, fabric filters capable of temperatures seen in coal-fired boilers are available in the US.

656. A number of other control technologies and combinations are employed in utility boilers. Table 8.4 summarizes most of the commonly used control technologies for North American utility (electrical generating station) boilers, and their effectiveness at reducing mercury and other polluting emissions,

while table 8.5 provides some more recent measurements of mercury emissions in the USA (US EPA, 2002).

Table 8.4 Control technologies used in North American utility boilers (NEG/ECP, 2000)

Technology	Mercury control effectiveness	Control of other pollutants	Availability and other notes
Selective Non-Catalytic Reduction	Unknown	30-60% NO_x reduction	Available and used on utility boilers. Minor reduced boiler efficiency.
Selective Catalytic Reduction	SCR + wet scrubber combination may result in substantial mercury reduction (see below)	70->90% NO_x reduction	Available and used on larger power plants. Minor reduced boiler efficiency. SCR catalyst may improve oxidation of elemental mercury to divalent mercury, which can be captured in a wet scrubber used for SO_2 control. The ability of SCR to improve the oxidation of Hg for capture in scrubbers may be highly coal-specific.
Low NO_x burners	None	>50% NO_x reduction possible	Available and in use on most coal-fired boilers. SCR and SNCR retrofits provide additional NO_x control beyond low-NO_x burners. It has been postulated that LNBs will improve mercury capture due to the increase in amount of unburned carbon (i.e., carbon loss on ignition [LOI]) in the flue gas stream that may act in a manner similar to activated carbon injection.
Coal Cleaning	0-78%	Average 48% reduction in SO_2 emission potential	Already done on most eastern and mid-western coal to reduce sulfur and improve boiler performance. Mercury removal varies widely, typically from 10% to 50% with mean removal rate of 21%. More advanced coal cleaning methods are under development.
Wet Scrubber	Up to 90% removal of oxidized Hg. No removal of elemental Hg	80->90% SO_2 removal	Already in use to reduce SO_2. Effectiveness for Hg removal highly dependent on mix of chemical species present and on other factors including liquid-to-gas ratio, chlorine content, and coal type.
Combined SCR with Wet Scrubber	>80% removal of overall Hg may be possible for units firing bituminous coals; effectiveness for units firing subbituminous coals is uncertain at this time.	>90% SO_2 and >90% NO_x removal possible	SCR already in use to reduce NO_x. Helps convert elemental Hg to soluble, oxidized form, thereby allowing for greater removal by downstream wet scrubber. Results are based on limited but encouraging data. The ability of SCR to improve the oxidation of Hg for capture in scrubbers may be highly coal-specific.
Dry scrubber with ESP or FF	6-9% reported by NEG/ECP; recent EPA studies reported average removal of approx. 63%)	80-90% SO_2 removal	In use on only 1% of US boilers (most units apply wet scrubbers). Removal efficiency for Hg depends on speciation, temperature, and chlorine content. Lime scrubbers show better Hg removal in pilot tests.
Electrostatic Precipitator (ESP)	0-82% (cold-side ESP) reported by NEG/ECP; EPA found 36% for bituminous and 3% for subitumninous (see Table 8-5)	>99% PM removal	Already in use for particulate removal. Cooler temperature improves ESP performance. US EPA found Hg removal efficiency of 42-83% on oil-fired boilers.
Fabric Filter (baghouse)	0-73% reported by NEG/ECP; EPA found 90% for bituminous and 72% for subbituminous (see Table 8-5)	>99% PM removal	Only filters providing particulate collection efficiencies >99% appear to reduce significant amounts of Hg, but data are limited. Again, lower temperatures appear to improve performance. Baghouses are more effective than ESPs in controlling mercury.
Enhanced ESP	0-50% at one test unit	>99% PM removal	Enhanced ESPs being developed to capture finer particles may remove more Hg. At one test unit Hg removal improved with lower temperature.
Wet ESP	Around 30% in 2 pilot scale studies	56% mean PM removal in pilot studies	Wet ESP being investigated for "polishing" residual emissions from other controls. May improve mercury removal. Lower temperature improves Hg control.
Combined ESP/Baghouse	34-87% in 2 pilot facilities	>99% PM removal	Combination technology to achieve very low PM emissions can improve removal of Hg & other toxics when used in conjunction with powdered activated carbon.

Technology	Mercury control effectiveness	Control of other pollutants	Availability and other notes
Carbon injection	Recent full-scale test results indicate about 80% removal with bituminous coal+ESP+COHPAC and 55-60% with subbituminous coal+ESP	Not applicable	Cost and removal effectiveness are directly related to the amount of carbon used. Used carbon may create a hazardous waste disposal issue. Carbon injection on utility boilers is currently under development and demonstration, but is not yet commercially deployed.
Fuel Switching	>99% for natural gas	>99% SO_2 and PM control; 50-75% NO_x reduction	Fuel switching reduces multiple pollutants, incl. NO_x, SO_2, particulates and CO_2. Accounting for multiple pollutant benefits reduces control costs for mercury alone. Cost affected by several factors, including fuel costs, other pollutant control costs, heat rate, facility age, capacity factor, new plant capital costs and discount rates.

Abbreviations:

SNCR -	Selective non-catalytic reduction	ESP -	Electrostatic precipitator
SCR -	Selective catalytic reduction	PM -	Particulate matter
LNB -	Low-NO_x burner		

Table 8.5 Recent measurements of mercury control technologies in the USA (US EPA, 2002)

Average Mercury Capture by Existing Post-combustion Control Configurations Used for PC-fired Boilers

Post-combustion Control Strategy	Post-combustion Emission Control Device Configuration	Average Mercury Capture by Control Configuration		
		Coal Burned in Pulverized-coal-fired Boiler Unit		
		Bituminous Coal	Subbituminous Coal	Lignite
PM Control Only	CS-ESP	36 %	3 %	-4 %
	HS-ESP	9 %	6 %	Not tested
	FF	90 %	72 %	Not tested
	PS	Not tested	9 %	Not tested
PM Control and Spray Dryer Adsorber	SDA+ESP	Not tested	35 %	Not tested
	SDA+FF	98 %	24 %	0 %
	SDA+FF+SCR	98 %	Not tested	Not tested
PM Control and Wet FGD System (a)	PS+FGD	12 %	-8 %	33 %
	CS-ESP+FGD	74 %	29 %	44 %
	HS-ESP+FGD	50 %	29 %	Not tested
	FF+FGD	98 %	Not tested	Not tested

(a) Estimated capture across both control devices

CS-ESP -	Cold-side electrostatic precipitator	SCR -	Selective catalytic reduction
FF -	Fabric filter	HS-ESP -	Hot-side electrostatic precipitator
SDA -	Spray dryer adsorber system	PS -	Particle scrubber
		FGD –	Flue gas desulfurization

657. Some control technologies typically serve to reduce emissions of more than one pollutant and, in fact, have been driven for the most part by acid rain emission controls. For example, wet scrubbers reduce both SO_2 and mercury. The technology for NO_x reduction (selective catalytic reduction, or SCR) has also been found to oxidize elemental mercury that can be effectively captured in a downstream wet scrubber. The conversion (fuel switching) of coal-fired boilers to burn natural gas (in a simple cycle gas-fired boiler or combined cycle gas turbine) offers great potential to reduce emissions of SO_2 and mercury (almost 100 percent) and NO_x (70 to 80 percent). Baghouses (FFs) and electrostatic precipitators (ESPs) control fine particles and some mercury, while the combination of the two substantially reduces mercury emissions. These are examples where multi-pollution controls may reduce mercury emissions, while specific mercury controls may not be economically feasible (NEG/ECP, 2000).

658. The US government, academics and industry are collaborating, with some Canadian support, on programmes to determine the extent of affordable mercury reduction from coal fired generating stations.

Conclusions regarding secondary emissions control

659. It must be remembered that the characteristics of the raw material, the combustion process (or other high temperature process), and the specifications of the control equipment all influence the eventual emissions of mercury from the exhaust generated by a given plant. For example, mercury captured with the fly ash from a bituminous coal-fired boiler equipped with an ESP or FF may range from 36 to 90 percent as seen in table 8.5. Similarly equipped plants burning sub-bituminous coal or lignite may exhibit fly ash related mercury removal ranging from 0 to 30 percent of the mercury with the fly ash. If the plant is also equipped with a wet FGD scrubber (and depending on the type of coal burned and the scrubber design), nearly all of the remaining Hg^{2+} can also be captured. Mercury removal levels as low as 10 percent and as high as 95 percent have been measured in the USA for coal-fired utility boilers equipped with wet limestone (FGD) scrubbers (US EPA, 2002). If coal cleaning is carried out prior to combustion, data from the US Department of Energy indicate that typically 10 to 50 percent of the mercury in coal can be removed only in the cleaning process (US EPA, 1998). Figure 8.3 provides a simple summary of the most common control technologies, while table 8.6 briefly reviews other common applications.

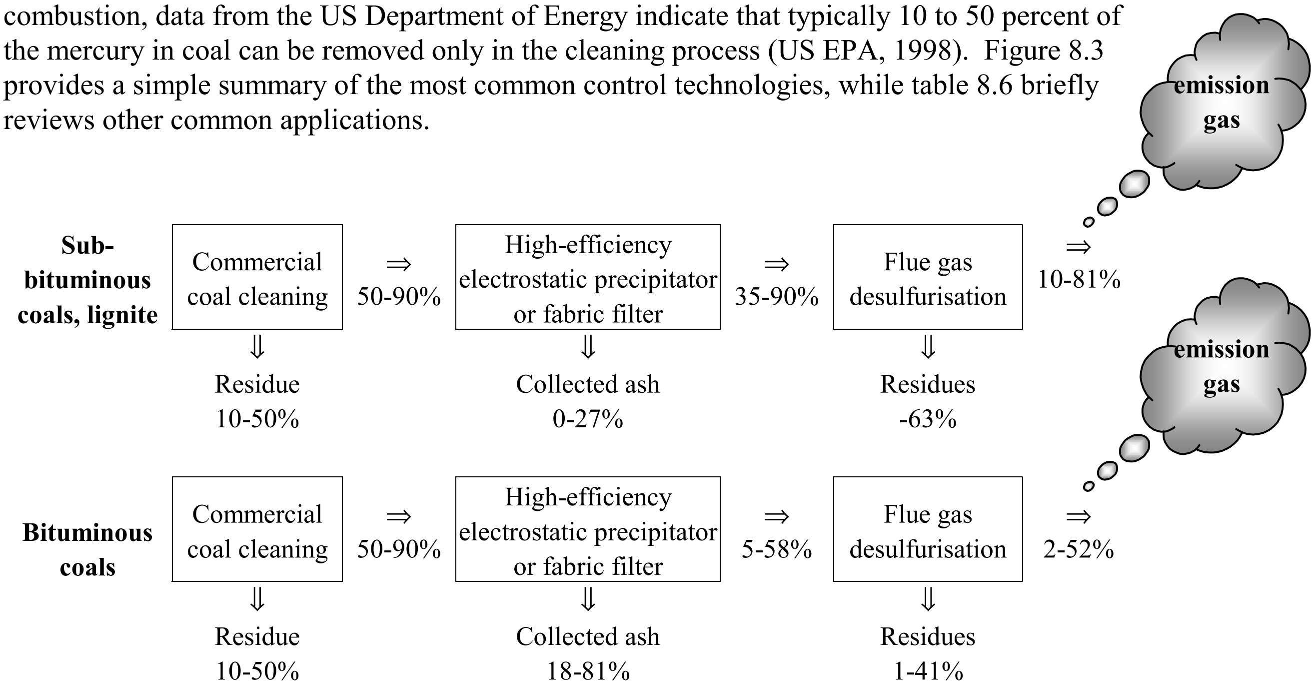

Figure 8.3 Reducing mercury emissions from utility boilers – typical efficiencies of key technologies

660. The mercury removal efficiencies in figure 8.3 may be compared with impressive results reported from a coal combustion unit in northeastern China, shown in figure 8.4.

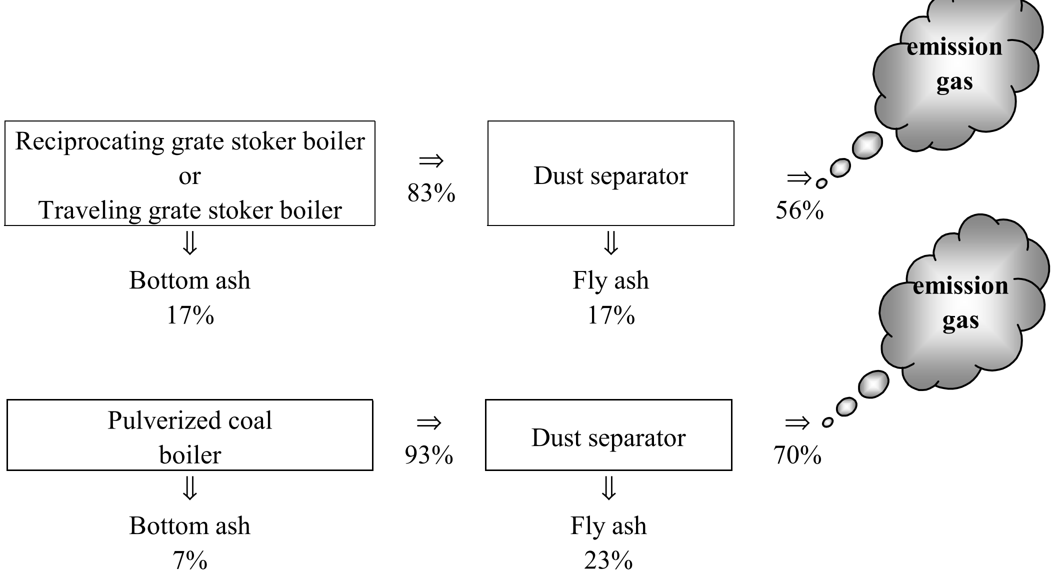

Figure 8.4 Reducing mercury emissions from coal combustion in China (Wang et al., 2000)

Table 8.6 Efficiency of common mercury control technologies for utility boilers (based on Pirrone et al.*, 2001)*

Emission source and choice of control technologies for utility boilers	Control combinations, effectiveness, final concentration of mercury in effluent, etc.
Coal-fired utility boiler emission controls a) wet flue gas desulfurisation (FGD) system b) spray dry FGD system c) downstream fabric filter ("baghouse") d) SO_2 absorption e) high-efficiency electrostatic precipitator (ESP) f) FGD wet lime/limestone-gypsum process with pre-scrubber	(a) achieves 30-50% reduction; potentially much better performance on bituminous coal-fired boilers. (b) achieves 35-85% reduction, in the higher range when supplemented by (c) (e)+(f) achieve 77% reduction (Netherlands) (e)+(b) achieve 75% reduction, of which 50-70% due to (e) (Bergstrom, 1983)
Coal fired utility boiler types and characteristics a) wet bottom boiler b) full burner load c) 50% burner load d) low burner load e) fluidized bed combustion f) pulverised coal-fired dry bottom boiler	(a) produces higher mercury emissions than alternative boilers (b) produces similar mercury emissions as (d) (c) produces half the mercury emissions of (b) and (d) (e) produces similar or lower mercury emissions than standard boilers (f) mercury emissions depend on coal type and control technologies used
Oil-fired utility boilers a) tangential unit b) horizontal unit	(a) and (b) have comparable mercury emissions

Abbreviations: ESP - Electrostatic precipitator FGD - Flue gas desulfurization

D. Control of incinerator emissions

661. Various countries rely to a greater or lesser extent on controlled waste **incineration**, which reduces the waste volume and (optimally) makes use of the energy contained in the waste materials. Because of its low boiling point, most of the mercury content of the waste evaporates during combustion, and is emitted directly to the atmosphere, unless the exhaust gas is properly controlled. In many countries emission controls on waste incinerators have been improved during the last decade, and this is reflected in decreased emissions of mercury (AMAP, 2000). In units fitted with control technologies, Pirrone *et al.* (2001) found that 35-85 percent of the mercury is removed by flue gas controls.

662. According to compliance tests recently conducted at 115 of the 167 large municipal waste incinerators, MWIs, in the USA, the average and median mercury control efficiencies for large MWIs were 91.5 percent and 94 percent, respectively. The average control efficiency at each site was based on a 3-test average determined by measuring the total flue gas concentration of mercury both before and after the control system at each site (injection of powdered activated carbon upstream of either a spray dryer and fabric filter baghouse, or a spray dryer and electrostatic precipitator).

663. The mercury eliminated from exhaust gases is retained in incineration residues and, for some types of filtering technology, in solid residues from wastewater treatment (from the scrubbing process). These residues are generally sent to landfills or – depending upon their content of hazardous materials and other characteristics – used for special construction purposes (wallboard, roadbeds or similar). In some cases such solid residues are stored in special deposits for hazardous waste, which are additionally secured with a membrane or other cover that eliminates or reduces releases by evaporation and leaching (Pacyna and Pacyna, 2000).

664. Typical control efficiencies for a municipal waste incinerator are shown in figure 8.5 below, and a greater range of common control measures in table 8.7. Note that additional releases from deposited ashes and residues are not reflected in the figure.

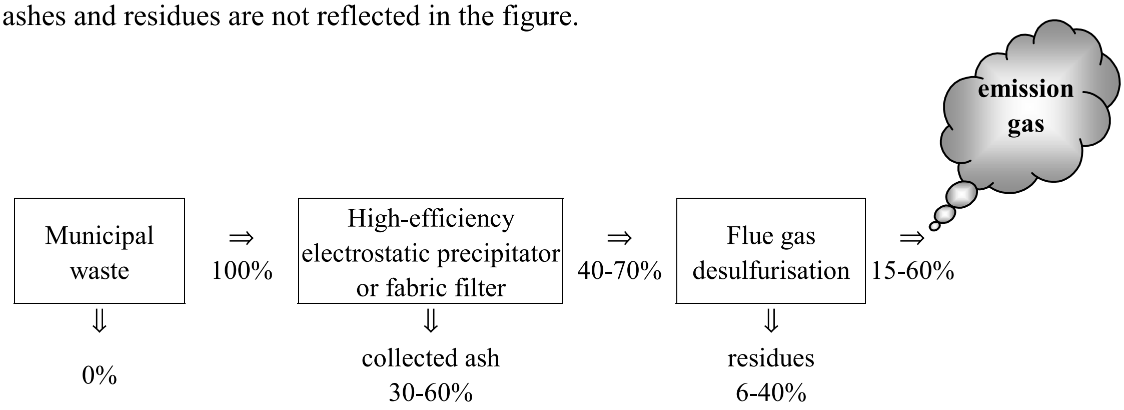

Figure 8.5 Reducing mercury emissions from waste incinerators – typical efficiencies of key technologies (based on Pirrone et al., 2001)

Table 8.7 Efficiency of common mercury control technologies for incinerators (based on Pirrone et al., 2001)

Emission source and control technologies for incinerators	**Control combinations, percent reduction of mercury emissions, final concentration of mercury in effluent, etc.**
Municipal waste incinerators (MWI) a) mass burn/waterwall (MB/WW) type of combustor b) high-efficiency electrostatic precipitator (ESP) c) spray dry FGD system d) downstream fabric filter ("baghouse")	(a) emits higher levels of mercury and compounds than other types of MWI (b)+(c) achieve 75% reduction, of which 50-70% by (b) (Bergstrom, 1983) (c) achieves typical 35-85% reduction, in the higher range when supplemented by (d)
Sewage sludge incinerators a) fluidized bed (FB) combustor b) multiple hearth (MH) technique	(a) emits lower levels of mercury to the atmosphere than other incinerators, and (b) emits more mercury than most

Abbreviations: ESP - Electrostatic precipitator FB - Fluidized bed
FGD - Flue gas desulfurization MH - Multiple hearth

Note: This table does not include the use of activated carbon injection as a control option. However, recent advances in the use of this technology are mentioned in previous paragraphs.

665. For comparison, figure 8.6 shows the behaviour of mercury in a specific Japanese incinerator (data provided by the Republic of South Korea). According to measurements, 98.2 percent of the mercury in the waste moves to the emission gas treatment facility, and only 2 percent remains in slag residues. Then, 14 percent of the mercury is removed by the electrostatic precipitator and remains in the collected ash and 91 percent of the mercury that passes the electrostatic precipitator (77 percent of total mercury) is removed by the gas cleaning facility. Finally, 7 percent of the mercury originally contained in the waste is emitted to the atmosphere.

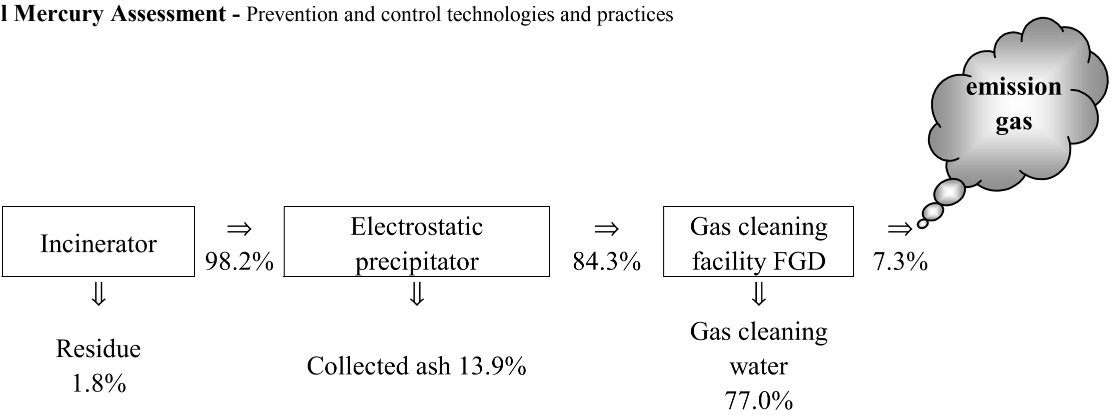

Figure 8.6 Behaviour of mercury in a Japanese incinerator (Nakamura, 1994).

8.3.4 Mercury removal from exhaust gases generated in industries other than utility boilers and incinerators

666. Processing of secondary raw materials such as iron and steel can also be a significant source of mercury emissions, and emission control technologies are often necessary. In this case the origin of the mercury may be from both natural impurities as well as from the intentional use of mercury in products/components (switches, air-bag activators etc.) that end up in iron/steel scrap.

667. Various techniques to remove mercury from exhaust gases generated by industries other than the production of electricity and heat, as well as during waste incineration have been developed, particularly for metallurgical processes. In one example, a selenium filter has been applied at both steel and non-ferrous plants. In this dry media process, mercury removal of 90 percent has been achieved, reducing the mercury concentrations to below 10 µg/m³. A carbon filter is also commonly used, with a mercury removal efficiency similar to that achieved with the selenium filter (Pacyna and Pacyna, 2000).

668. The lead sulfide process is another dry media technique used to remove mercury from flue gases generated in non-ferrous metal smelters. The gases containing volatile mercury are passed through a tower packed with lead-sulfide-coated balls. One study at a Japanese smelter in Naoshima indicates reduction of mercury concentrations from 1000–5000 µg/m³ in the feed to the absorption tower to 10-50 µg/m³ at the outlet (Pacyna and Pacyna, 2000).

669. The two major wet media processes to remove mercury from flue gases include the selenium scrubber and the so-called Odda chloride process. The selenium scrubber method is rather similar to the selenium filter technique. A mercury reduction of 90–95 percent can be achieved (Pacyna and Pacyna, 2000).

670. In the Odda chloride process, mercury vapours are oxidized to form mercuric chloride, which then precipitates. Mercury is recovered and mercuric chloride is regenerated. The mercury concentrations of the treated gases are 50-100 µg/m³ (Pacyna and Pacyna, 2000).

671. The effectiveness of these techniques is summarized in table 8.8, and other common technologies are reviewed in table 8.9.

Table 8.8 Efficiency of flue gas mercury removal techniques (Pirrone et al.*, 2001)*

Control technique	**Typical Hg removal efficiency**	**Measured Hg content downstream (µg/m³)**
Selenium filter	> 90%	< 10
Selenium scrubber	90-95%	200
Carbon filter	90-95%	10
Odda chloride process	n.a.	50-100
Lead sulfide process	90-99%	10-50

Table 8.9 Efficiency of mercury control technologies for other industries (based on Pirrone et al.*, 2001)*

Emission source and control technologies	**Control combinations, percent reduction of mercury emissions, final concentration of mercury in effluent, etc.**
Iron and steel industry a) electric arc (EA) process (normally used for special alloy steels and scrap) b) basic oxygen (BO) process c) open hearth (OH) process d) dry media selenium filter e) carbon filter process f) wet media selenium scrubber g) wet media Odda chloride process	(a) emits 10 times more trace elements than (b) or (c) (d) achieves up to 90% reduction of mercury emissions, to less than 10 µg/m³ (e) achieves up to 90% reduction of mercury emissions, to less than 10 µg/m³ (f) achieves 90-95% reduction of mercury emissions (g) may reduce mercury emissions to 50-100 µg/m³
Non-ferrous smelting processes a) dry medium selenium filter b) carbon filter process c) dry media lead sulfide process d) wet media selenium scrubber e) wet media Odda chloride process	(a) achieves up to 90% reduction of mercury emissions, to less than 10 µg/m³ (b) achieves up to 90% reduction of mercury emissions, to less than 10 µg/m³ (c) may reduce mercury concentrations from 1000-5000 µg/m³ before the absorption tower, to 10-50 µg/m³ of emissions at the outlet

8.3.5 Reducing releases of mercury from chlor-alkali facilities

672. In mercury cell chlor-alkali plants, mercury is used as a flowing cathode in electrolytic cells. Specific details of this process may be found in Lindley (1997), EIPPCB (2000) and various other references. Most releases of mercury from this process occur with the hydrogen gas, the end-box ventilation system and the electrolytic cell room ventilation air (US EPA, 1973).

673. Mercury releases from chlor-alkali operations can be entirely eliminated only by converting to a non-mercury process such as the membrane cell process. The fact that the membrane cell process is more energy efficient (Fauh, 1991) is one of several strategic and economic considerations that must be taken into account when a company decides to dismantle a mercury cell chlor-alkali facility and replace it with membrane technology.

674. When a mercury cell process is converted to a membrane cell process, certain parts of the process may remain the same. However, because residual mercury levels exceeding 10 parts per million (ppm) in the brine system can greatly affect membrane performance (O'Brien, 1983), a mercury removal system is required initially. The mercury removal process is needed until residual mercury is sufficiently purged from the brine (typically 1 or 2 years). The filters used for mercury removal can later be used for secondary brine treatment (Horvath, 1986). There are many other technological changes also required when making a conversion from mercury to membrane technology – although the complexity and cost of these are highly dependent on the circumstances of the individual plant. A typical example is the need for brine of far higher quality for the membrane process. Supply of such brine often requires the installation of a new brine purification plant, and may also require a change of raw material source.

675. As mentioned, there are electricity savings associated with plant conversion, as well as other operating cost savings such as the avoidance of costs of recycling or disposing of mercury wastes, although these costs are uncertain (US EPA, 1997). While the actual figures are highly plant dependent, the World Chlorine council has suggested that most estimates for total operating cost savings fall in the range of $US30 to $50 per metric ton of chlorine capacity. These savings, accrued over the plant's lifetime, may be compared with the initial investment cost of conversion, which may typically be on the order of $500 per metric ton of chlorine capacity.

676. Other than complete conversion to an alternative process, primary opportunities for reducing atmospheric mercury emissions from the mercury cell chlor-alkali production process require paying particular attention to the by-product hydrogen stream, end-box ventilation air, and cell-room ventilation air. Typical devices/techniques for removal of mercury from stack emissions are: 1) gas stream cooling to remove mercury from the hydrogen stream, 2) mist eliminators, 3) scrubbers, and 4) adsorption on activated charcoal and molecular sieves. The proper use of these devices can remove more than 90 percent of the mercury from the gas streams (Pacyna and Pacyna, 2000).

677. However, most mercury losses from chlor-alkali facilities are fugitive. Relevant preventive measures include:

- Equipment cool-down before opening for invasive maintenance;
- Consolidation of maintenance actions to minimize the number of invasive maintenance events;
- Draining mercury from a components before it is opened or keeping its internal mercury covered with cooling water or installing a hood to capture mercury vapour;
- Capital investment in larger-capacity decomposers that require less invasive maintenance;
- Improving the purity of brine so as to prevent build-up of mercury wastes that require invasive maintenance;
- Use of longer-lasting metallic anodes that necessitate less invasive maintenance;
- Capital investment in new elongated cells with air pollution prevention features like internal mechanical arms that can accomplish some maintenance actions that formerly required invasive maintenance.

678. Further comprehensive information on relevant abatement options can be found in EIPPCB (2000) in “Guidelines for Mercury Cell Chlor-alkali Plants Emission Control: Practices and Techniques,” at <http://www.cl2.com/AM2001/index.html>, and in a similar series of guidelines and documents available on the Euro Chlor site at <http://www.eurochlor.org/>.

679. As an example of recent progress in this area, the US mercury cell chlor-alkali companies have voluntarily reduced mercury consumption by 81 percent since 1995 to about 28 metric tons in 2001. Adjusted for a decline in production capacity during that period, the “real” decrease was 75 percent. According to industry reports, these reductions have been made through a variety of equipment upgrades and improvements to housekeeping practices that have limited the vaporization of mercury from the mercury cell room. Likewise, using similar technological improvements and changes in management practices, the industry in Western Europe has voluntarily reduced mercury emissions to the atmosphere[24] by 96 percent since 1977.

8.3.6 Reducing mercury releases from artisanal gold mining operations

680. According to CETEM/IMAAC/CYTED (2001), since 1980 small-scale gold mining activities have increased steadily. This report also estimates that small-scale mining may account for as much as one-quarter of the world gold output. Despite the current low gold price, the gold rush in the artisanal sector continues. Chapter 7 has documented the importance of mercury releases from these activities. UNIDO’s participation and objective in addressing this problem is to replace low-recovery, high-mercury-consuming and -discharging processes with environmentally safe and high-yield gold extraction alternatives that will sharply reduce or eliminate the use and discharge of mercury.

A. Diverse measures to reduce mercury releases and exposures

681. According to CETEM/IMAAC/CYTED (2001), since training and awareness-raising are important tools for getting results in the small-scale mining sector, UNIDO focuses on:

- On-the job training in cleaner technology;

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[24] While mercury emissions to the atmosphere (European industry data) cannot be directly compared to mercury consumption (US industry data), the main point of this paragraph is that a large part of the industry has made a serious effort to improve its environmental performance.

- Training of women and women entrepreneurs, who have a big share in the sector;
- Enhancing awareness through workshops on local, regional and international level;
- Raising the interest of the media. Among others, BBC and CNN have already reported on the mercury-related activities of UNIDO.

682. In order to successfully introduce alternatives to present polluting practices, one needs to:

- Familiarize local manufacturers with the design of low-tech but efficient gold recovery equipment;
- Demonstrate alternatives to amalgamation;
- Prove the cost effectiveness of the new techniques;
- Develop micro-financing programmes in cooperation with the private sector.

683. The involvement and commitment of the local community is crucial, including the following elements:

- Clear community understanding of the problem;
- Commitment of community resources to deal with it;
- Meetings of all the stakeholders involved in the discussions to reach a consensus:
- After consensus is reached, a programme of action including: a) closed circuit utilization of mercury in the concentration/amalgamation steps; b) burning of the amalgam in retorts in the field, and use of fume hoods in gold dealers' shops; and c) confinement of processed material in specially built settling ponds;
- Agreement to adopt these measures both for the present operations and to avoid future problems;
- For the present operations, sampling the levels of mercury pollution, assessing risk areas, and carrying out isolating and remediating measures to ensure mercury fixation and/or recovery.

684. Other more obvious measures should also be implemented, such as:

- No spilling of mercury during the amalgamation phase, being a matter of mercury management throughout the process;
- Use of amalgamation vessels;
- Processing of the ore in a closed loop;
- Use of retorts in order to collect the mercury vapours;
- Use of fume hoods (preferably with carbon filters) at gold shops.

685. For a field manual on how to process alluvial gold ores and manipulate mercury safely, see CETEM (1994).

B. Amalgamation centers

686. UNIDO (1997) has noted that a very creative solution has been implemented in Venezuela - Amalgamation Centers. This solution can be easily reproduced in other countries. Miners take their gravity concentrates to these centers to be safely amalgamated by technical operators. In the Amalgamation Centers in Venezuela operated by the government, the service is free. In private centers, miners pay US$ 0.7 per kg of concentrate to be amalgamated.

687. Based on the Carhuachi Center, a remarkable Amalgamation Center at Caroni River, UNIDO and a Venezuelan non-governmental organization known as PARECA designed a center called UNECA (UNit for gold Extraction and Controlled Amalgamation). At the center, gold is processed by trained operators using special amalgamation plates or leaching using the NaCl electrolytic process. Both methods reduce the use of mercury. The electrolytic process actually eliminates amalgamation. Special retorts and melting furnaces working under fume hoods with charcoal filters impregnated with iodine are used.

688. The UNECA-type amalgamation center is suitable for installation in mining villages or in any central area to facilitate miners bringing gravity concentrates. Gold recovery is actually improved and mercury exposure to the operators is insignificant. For a miner who takes his concentrate to an amalgamation center, there is the added benefit of reducing costs in his own processing plant. These centers play an important role in diffusing information about mercurialism caused by mercury vapour and ingestion of contaminated fish. Miners can be given information while they wait for the processing of their concentrates. The centers can also provide advice for miners on how to improve their production, and can provide a meeting place for other purposes of education and organization.

C. Individual measures

689. Other measures may be focused directly at the individual artisanal miner to reduce his/her releases of mercury. Retorts can be used to capture volatilized mercury and condense it, resulting in substantial reductions in air emissions and occupational exposures, and allowing the mercury to be recycled a couple of times before its capacity to recover gold has been too much reduced. Some retorts are made of stainless steel while others are homemade of inexpensive iron pipes and connections. Mercury losses during retorting depend on the type of connections or clamps used, and the mercury recovery is typically 51-99 percent (Farid *et al.*, 1991). Retorts are not widely used in the goldfields because of uncertainty among the miners about what may happen to the gold when they do not have continuous eye contact with the amalgam during the retorting process. There is some fear that the temperature might be so high that the gold also evaporates, or that the gold may somehow be stolen. Moreover, after so many hours of hard work it is thrilling to watch every step of the transformation of the amalgam to gold. Finally, those who profit from selling mercury have been reported actively discouraging any such innovation that may reduce their market.

690. Other methods for abating mercury emissions when an amalgam is heated are also available and can be easily implemented. According to UNIDO (1997), already in 1989 a Brazilian company had developed a mercury condensing fume-hood. The prototype had a series of condensing plates coupled with activated charcoal filters impregnated with an iodine solution. More than 99.9 percent of mercury from the fumes were reported to be retained by this special fume-hood. Less than 40 µg/m^3 of mercury was detected in the interior of the shop during a gold smelting operation, compared with other measurements as high as 300 µg/m^3 in unprotected shops[25]. A similar technique was used by the Amalgamation Center of Carhuachi in Venezuela. This simple solution should be applied to all gold dealers in Latin America, which will result in a significant reduction of mercury emissions in urban areas.

8.4 Waste management practices

8.4.1 Mercury wastes and inventories

691. As described in chapter 6, mercury in waste can be a significant source of mercury releases, especially as waste management practices vary considerably around the world. Recalling from chapter 6, the diversity of waste streams that need to be carefully monitored are summarized in table 8.10. In addition, there are some very large inventories of mercury that could give rise to significant releases if not managed responsibly, see table 8.11.

692. In one example, the US Department of Defense “strategic” stockpile of virgin mercury was decided to be sold in the early 1990’s. US EPA subsequently convinced the defence department to delay further sales until some sort of control system could be worked out to prevent eventual uses that could not be adequately controlled. The delay remains in place, but no long-term solution has yet been found.

693. In a second example, chlor-alkali mercury poses a special challenge (see also section 7.4). As plants are decommissioned in Western Europe, “used” mercury is becoming available in large quantities - about 500 metric tons per year in 2000 and 2001, according to Euro Chlor. This mercury is virtu-

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[25] For comparison, background atmospheric mercury in cities is about 0.01 µg Hg/m^3, the limit for public exposure is 1 µg Hg/m^3 and the limit for industrial exposure is 50 µg Hg/m^3 (UNIDO, 1997).

ally "pure" and therefore reusable (for most applications) without reprocessing. The European Commission was asked by the Environment Council (meeting 7 June 2001) whether some sort of coordinated action is necessary within the EU member states in order to control the eventual fate of this mercury. The industry has agreed for the present to put it under the control of the Spanish mining company Miñas de Almadén on condition that it replaces, ton-for-ton, mercury that would otherwise have been newly mined and smelted to satisfy normal market demand.

Table 8.10 Waste streams giving rise to mercury releases

Waste emissions of mercury to the atmosphere
▪ Incinerator waste water treatment plant sludge ▪ Diffuse releases from uncollected waste products (fluorescent lamps, batteries, thermometers, mercury switches, electrical and electronic components, lost teeth with amalgam fillings etc.) ▪ Evaporation of mercury disposed of in landfills ▪ Mercury wastes that go to municipal, medical or hazardous waste incinerators ▪ Mercury contained in scrap metal used in secondary metal production ▪ Mercury emissions from other treatment processes, including retorting facilities and stabilisation
Waste discharges of mercury to water – aquatic environment
▪ Direct discharges from industry and households to water drains ▪ Indirect discharges via waste water treatment systems ▪ Informal disposal in the water, and surface run-off from informal disposal on land ▪ Leachate from landfills without leachate collecting membranes and leachate effluent cleaning systems
Waste releases of mercury to the soil – terrestrial environment
▪ Disposal on land (informal) or in landfills – with or without protection of groundwater and surrounding soil (membranes and leachate water cleaning system) ▪ Diffuse releases from uncollected waste products (batteries, thermometers, mercury switches, electrical and electronic components, lost teeth with amalgam fillings etc.) ▪ Local releases from industry: On site materials and waste storage, broken/unused pipes, equipment and building materials ▪ Spreading of sewage sludge with trace contaminants on agricultural land (used as fertiliser) ▪ Use of solid residues from waste incineration and coal combustion for construction purposes (slag/bottom ash and fly ash)

Table 8.11 Key inventories of mercury that must be responsibly managed

Waste quantities or inventories of mercury that need to be managed
▪ So-called "strategic" mercury stockpiles held by a number of governments ▪ Large quantities of mercury recovered from mercury-cell chor-alkali facilities at the time of decommissioning or changing to a non-mercury process

8.4.2 Prevention and control measures

694. Since all of these sources of (potential) mercury releases have been previously described, this section will focus primarily on the sorts of measures that may be applied for preventing (long-term solutions) and controlling (usually short- to medium-term solutions) those releases. Many problems might be simplified, of course, if mercury substitutes were more widely used and the mercury content of various waste streams were much reduced. However, this chapter assumes that the mercury is already in the waste, and then suggests how best to deal with it. As in the case of industrial releases, one may consider a range of non-technical and technical measures that might be applied.

A. Non-technical measures

695. Non-technical measures for preventing and controlling releases from waste streams may typically be divided among regulatory/prescriptive measures, economic measures, and educational/information measures. Some examples follow.

(1) Regulatory/prescriptive measures

- Prohibit mercury in product waste and in process waste from being released directly to the environment, by means of an effective waste collection service;
- Prohibit mercury in product waste and in process waste from being mixed with less hazardous waste in the general waste stream, by ensuring separate collection and treatment;
- Set limit values for the allowable mercury content in sewage sludge spread on agricultural land;
- Restrict the use of solid incineration residues in road-building or other applications where its long-term control cannot be assured;
- Prohibit the re-marketing of used, recycled mercury;
- Prohibit illegal dumping of wastes;
- Prohibit any direct or indirect discharges of mercury to normal drains or the water treatment system, or any disposal of mercury in water;
- Prohibit or restrict cross-border transport of mercury (and other hazardous) wastes;
- Require that any mercury containing waste or materials stored on-site by an industry or commercial operation must be in air-tight and waterproof containers, and that the organization must have a written plan and schedule for eventual proper disposal of the materials;
- Prohibit the disposal on land of any sewage sludge, fertilizer, or other material that exceeds responsible international standards for mercury content;
- Put in place an environmental management strategy that includes responsible monitoring and enforcement of mercury regulations, tracking of all mercury movements (from raw material to process to product to waste), and periodic independent control.

(2) Economic measures

- Set taxes and fees on hazardous waste disposal (special incineration, dedicated landfill, etc.) that fully reflect the real long-term costs to society and the environment of responsibly dealing with these hazardous substances.

(3) Information and educational measures

- Educate the public about proper disposal of mercury containing products;
- Provide collection points where the public may easily take these separated products;
- Devise several key indicators and publicize the progress that is being made with regard to responsible management of mercury.

B. Technical measures

696. Technical measures for dealing with mercury wastes may be divided between pre-treatment measures and emission control measures.

(1) Pre-treatment measures

- Prohibit or limit mercury releases to the environment by treating household waste, hazardous waste and medical waste by emission control technology.

(2) Emission control measures

- Require landfills to be properly licensed and equipped for the type of hazardous waste they accept, including membranes to prevent mercury from evaporating or leaching, collection and treatment of landfill effluent, routine and long-term testing of groundwater quality, air emissions, etc.;

- Ensure that mercury wastes are incinerated only at facilities equipped for hazardous waste, with best-available-technology dust collectors and flue gas control, etc.;
- Develop a facility (perhaps jointly with a neighboring country) for final disposal of mercury (and other) treated wastes that are so concentrated or hazardous over the long term that they cannot be responsibly disposed of in another manner.

C. Limited long-term solutions

697. As explained in chapter 6, most of the options above are short- to medium-term measures. One of the only real long-term measures is prevention (keeping mercury out of the waste stream). Once present in the waste stream (if pollution control is considered a priority), mercury contributes to the need for emission controls on incinerators, special disposal of incinerator residues, landfill leachate treatment etc. – all associated with extra costs. Even those countries that make an effort to separate mercury products from the general waste stream have found it difficult to achieve satisfactory collection rates, and they have discovered that separate collection and treatment implies significant extra costs for society. Therefore, with regard to mercury in products, minimising the intentional use of mercury may be a highly desirable objective. This has been the main driving force behind the mercury substitution policy of many countries.

698. Another long-term measure for mercury waste management is intermediate storage/definitive storage in a special facility, such as that described below.

8.4.3 Responsible management of mercury inventories

A. Take-up by Almadén

699. As described in chapter 7, one of the solutions proposed for mercury from decommissioned chlor-alkali facilities is shipping it to the Almadén mercury mine in Spain, which has agreed to decrease its mining production and to market the chlor-alkali mercury instead. Some feel that there are not yet adequate controls on where this mercury would then be sold by Almadén, or how it would be used.

B. Intermediate storage

700. Another proposal is that the mercury could be stored safely for an indefinite period of time until a strategy for closed-loop re-use or safe disposal is available. This option has the advantage that the mercury would be available if some important new need is identified. It could lead to some releases, ongoing management costs, and is still not a final solution. However, ongoing management costs and the risk of significant releases outside the intermediate storage enclosure would be small if best management practices were implemented.

C. Terminal/permanent storage

701. It has been argued that, from an environmental point of view, terminal/permanent disposal of mercury would be preferable. However, this could encourage continued mining and smelting of virgin mercury to meet ongoing demand. Further, it has been argued, the deposited mercury could be difficult if not impossible to recover if important new (and "closed-loop") uses were to emerge in the future.

702. Sweden has developed a strategy for terminal storage of surplus mercury and mercury containing waste. The strategy was developed as a response to concerns about what to do with the mercury collected from consumer products, industry and high-level mercury waste, which is currently in intermediate/provisional storage. Although the legal framework needs to be developed, and there are various technical issues related to waste treatment that need to be worked out, as well as the location and design of the terminal storage facility, a viable concept has been developed and proposed. The concept includes a suggestion that the waste owners bear full responsibility for constructing, managing and operating the facility. Excluding pre-treatment, estimates of the eventual cost of this option are on the order of $US 14-20 per kg of mercury. To put this figure in some perspective, this terminal storage cost

would add 6-10 percent to the estimated cost of converting a chlor-alkali facility from the mercury process to the membrane process.

703. The terminal storage concept is based on the conversion of mercury, currently stored in the elemental form or as high-level mercury containing waste, to a chemically stable form (e.g. mercuric sulphide, HgS), and subsequent disposal of the stabilised mercury in deep-rock storage. A number of investigations of waste treatment technology, chemical stabilisation, geochemistry, geohydrology and economics have been carried out, and the results of these investigations indicate that the concept is technically and economically feasible.[26] Although a range of issues remain to be addressed, the terminal storage strategy is scheduled for implementation in the near future in Sweden.

704. While other options for waste treatment and facility design will also be considered, at present the main components of the proposed terminal storage concept are:

- Conversion of mercury from high-level waste, batteries, electrical devices, etc., to the elemental form via thermal treatment and condensation of liquid elemental mercury;
- Conversion of the elemental mercury to the sulphide form via thermal treatment with, e.g., sodium sulphide or other suitable reagents;
- Storage of the mercury sulphide in a deep-rock storage facility equipped with appropriate monitoring devices.

705. Physical requirements for the terminal storage facility include geological stability, low water permeability, and absence of mineral resources which are or may become economically feasible to excavate. The terminal storage may be located in an abandoned mine shaft with well known geological and geohydrological characteristics.

706. It is important to note that the concept of deep-rock terminal storage was not developed as a method to reduce current mercury releases to the environment or current exposures. Rather, it was designed as a long-term solution to the problem of storing mercury wastes - in light of the persistence of mercury and the need for long-term strategies to reduce mercury pollution.

8.5 Mercury control costs and effectiveness

707. While the costs of control technologies are highly variable, depending on the country and location, local circumstances, availability of equipment and technicians, characteristics of raw material being combusted or waste being incinerated etc., this section draws on several key sources to provide some comparative estimates of these costs.

8.5.1 Costs of reducing mercury emissions from boilers and incinerators

A. Mercury control costs for utility boilers

708. As mentioned on page 14 of NEG/ECP (2000), "[US EPA] estimates of the cost effectiveness of various mercury emission reduction approaches vary widely," from $US 11-66 per gram of mercury removed using carbon injection,[27] to $US 143-933 per gram of mercury removed for fuel switching. These figures may appear high compared to general costs for reducing conventional pollutants such as

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[26] In early 2002, US EPA completed its own research on mercury treatment by stabilisation and amalgamation. Two samples were used in this research – elemental mercury and a mercury waste containing 5000 ppm of a variety of mercury species. Based on the results of these studies, US EPA does not believe that treatment alone is sufficient for the long-term management of mercury wastes containing high levels of mercury, and for excess mercury inventories. US EPA is not convinced the wastes will remain in a stable condition when exposed to the full range of landfill conditions that exist in the USA.

[27] US EPA estimated this range of costs for carbon injection on a coal-fired, 975 MW boiler at a 90 percent mercury removal rate. Note that while NO_x control costs are applicable to full-scale applications, mercury control costs are based on pilot-scale data and, therefore, are more developmental in nature. Data from ongoing full-scale demonstrations are expected to refine mercury control costs.

nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter (PM). While any such comparison must be carefully interpreted due to the entirely different nature of the emissions, quantities, effects, etc., US EPA has presented a comparison as summarized in the box below.

Comparison of Mercury and NO_x Control Costs (US EPA, 2002)

An understanding of mercury control costs may be gained by comparing them with costs of currently used controls for NO_x. In the USA, commercial NO_x control technologies are being used to comply with emission reduction requirements. Therefore, the costs associated with these NO_x controls are being experienced at full-scale applications. A comparison of mercury control costs with costs of currently used NO_x controls provides insight into how far or near the mercury control costs are from costs that are presently being experienced at full-scale applications to control another pollutant.

Table 8-10 below presents the ranges of total annual costs in 2000 constant dollars for the mercury controls examined in this work and for two currently used NO_x control technologies; i.e., low NO_x burner (LNB) and selective catalytic reduction (SCR). The NO_x control costs presented are for applications on dry-bottom, wall-fired pulverized-coal boilers ranging in size from 100 to 1000 MW and being operated at a capacity factor of 0.65. In general, costs associated with LNB and SCR are expected to span the costs of currently used NO_x controls; therefore, these costs were chosen for comparison with mercury control costs.

As seen from Table 8-10 below, total annual costs for mercury controls lie mostly between applicable costs for LNB and SCR. However, Table 8-9 (*not shown here*) shows total annual costs of mercury controls to be higher for the minority of plants using HS-ESPs (hot-side electrostatic precipitators). Excluding these costs, both currently estimated and projected mercury control costs are in the spectrum of LNB and SCR costs.

Table 8-10

Air pollutant controlled	**Control technology**	**Total annual control cost range ($US/MWh generated)**
Hg	Powdered activated carbon injection	0.305 to 3.783 (a) 0.183 to 2.270 (b)
NO_x	Low- NO_x burners	0.210 to 0.827 (c)
	Selective catalytic reduction	1.846 to 3.619 (c)

(a) current estimate of costs (b) projected costs (c) actual costs

709. It is important to recognize that the ultimate cost of controlling mercury from utility boilers will be dependent upon the potential impact that mercury control has on the sale and/or disposal of the combustion by-products. For example, for plants that sell their fly ash for cement manufacturing, the use of activated carbon injection could dramatically reduce their ability to sell this material due to increased carbon concentrations. For plants that elect to use a wet scrubber to capture mercury, their ability to sell their gypsum for use in wallboard manufacturing could be compromised by increased concentrations of mercury. The potential impacts of additional mercury control on the use of by-products or the disposal of residues have not yet been determined. Such considerations may significantly affect an operator's costs of controlling mercury emissions from coal-fired boilers.

710. It must also be mentioned that mercury presents a far greater health and environmental hazard on an equivalent weight basis than do SO_2, NO_x, and PM. The costs are more similar to those associated with the control of dioxins and furans, which are produced in flue gases in extremely small quantities, and where any emissions at all are a concern. As is the case with effective controls of these compounds (scrubbers and baghouses are very effective at capturing dioxins and furans), it is important to note that many mercury control strategies also reduce other pollutant emissions, and vice versa. Fuel

switching, for example, can dramatically reduce emissions of NO_x, SO_2, carbon dioxide (CO_2), and particulates, while scrubbers remove many other toxics in addition to mercury. When the costs of these strategies are allocated among all the pollutants reduced, their cost-effectiveness is much improved.

711. Summary information on relative control technology costs is provided in table 8.12. This table indicates an apparent cost-effectiveness advantage for activated carbon injection, with the caveat that additional equipment is needed to remove other pollutants. However, it also demonstrates the popularity of the combination of electrostatic precipitator (ESP) or fabric filter (FF) and wet flue gas desulfurization (FGD), for which the initial investment (for a plant approaching 1000 MW capacity) is about $US 25 million greater, but operation & maintenance costs are nearly $US 6 million/yr less than for activated carbon injection.

Table 8.12 Rough cost-effectiveness of mercury control measures for utility boilers (based on Pirrone et al.*, 2001). Please refer to the source for further details.*

Control options for utility boilers	**Mercury removal efficiency (percent)**	**Costs**	
		Investment ($US 1000/MW)	**Operation & maintenance ($US 1000/MW/year)**
ESP only	10**	1.6	0.2
FF only	29**	28.9	5.8
ESP or FF + wet FGD	85	59.0	2.5
SDA + ESP	67	143.	5.0
ESP + carbon filter bed * [Based on the costs noted, this is not a practical option]	90-95	264.0	62.0
Activated carbon injection + FF *	50-90+	34.6	8.1

* Mercury control technologies.

** On the basis of previous discussions, this number appears low.

Abbreviations:				
	ESP -	Electrostatic precipitator	SDA -	Spray dryer absorber
	FF -	Fabric filter	MW -	Megawatt
	FGD -	Flue gas desulfurization	MWh -	Megawatt-hour

B. Mercury control costs for incinerators

712. Incinerators employ many of the same mercury control technologies used in utility boilers. However, the cost structure is much different, so it is useful to present them in a separate table, and to compare incinerator control costs with other incinerator control costs rather than with utility boiler control costs. Once again, it should be kept in mind that the costs calculated in table 8.13 assume that the entire cost of emission controls is allocated to mercury alone, which is clearly not representative of the real world situation. Each of the control options discussed in the table has some effect on greenhouse gases and other emissions, and these effects must be taken into consideration before final decisions on multi-pollutant control technologies are made.

713. In conclusion, the relative costs and mercury removal effectiveness of the most common control technologies applied to incinerators are presented in table 8.14. In this case activated carbon injection seems to clearly lead the field in cost effectiveness, although its ability to remove other pollutants from the flue gas is greatly limited. It is therefore combined with an electrostatic precipitator or a fabric filter.

Table 8.13 Control technologies and cost effectiveness for incinerators (US EPA, 1997)

Source	Mercury control technique	Cost effectiveness		Cost comments
		$US/g Hg removed	Other indicators	
Municipal waste combustor (MWC)	Material separation (batteries)	$3.19	$0.41/metric tons MSW	Costs very community specific; results shown based on one community's program.
	Product substitution (e. g., batteries, thermometers etc.)	[see comment]	[see comment]	The potential for product substitutions requires that the specific circumstances of each situation be examined; general cost estimates are not possible.
	Activated carbon injection	$0.46 – 1.92	$0.77-3.85 metric tons MSW	Costs assume an 85% reduction; the range of costs covers two model plants. Costs equivalent to 1.3% (large unit) to 6.9% (small unit) calculated cost increase*
	Carbon filter beds	$1.13 – 2.39	$5.98-10.33/metric tons MSW	Range of costs covers two model plants.
	Polishing wet scrubber	$3.52 – 7.31	$5.83-14.85/metric tons MSW	Costs assume an 85 percent reduction; range of costs covers two model plants.
Medical waste incinerator (MWI)	Material separation (batteries)	less than $3.19 [see comment]	less than $0.41/metric tons MSW [see comment]	Costs vary on a site-specific basis; no costs were available; cost effectiveness for a hospital program would be assumed to be better than for a community program.
	Good combustion, wet scrubber or dry scrubber with carbon injection	--	--	For cost- effectiveness estimates for individual facilities, the reader should consult *Hospital/ Medical/ Infectious Waste Incinerators: Background Information for Promulgated Standards and Guidelines - Regulatory Impact Analysis for New and Existing Facilities* (EPA- 453/ R- 97- 009b)
	Switching with waste segregation		0.01-0.04% calculated cost increase*	
	Switching without waste segregation		0.02-0.09% calculated cost increase*	

* "Calculated cost increase" is the estimated cost increase in the service or product to cover the cost of these emission controls.

Abbreviation: MSW - municipal solid waste

Table 8.14 Cost-effectiveness of mercury control measures in waste incinerators (based on Pirrone et al., 2001) (ton = metric ton)

Control option	Mercury Removal efficiency	Costs			
		Investment		Operation & maintenance	
Municipal waste combustor	**(percent)**	**($US 1000/ton waste)**		**($US 1000/ton waste/yr)**	
capacity of MWC		**~180 t/day**	**~2000 t/day**	**~180 t/day**	**~2000 t/day**
ESP only	10	n.a.	n.a.	n.a.	n.a.
FF only	29	n.a.	n.a.	n.a.	n.a.
ESP or FF + carbon filter bed	99	31.7	80.0	6.5	15.6
Activated carbon injection + ESP or FF	50-90+	0.3	0.8	0.25	1.3
Polishing wet scrubber + ESP or FF	85	10.3	22.9	1.9	4.9
Medical waste incinerator	**(percent)**	**($US 1000/ton waste)**		**($US 1000/ton waste/yr)**	
capacity of MWI		**~60 kg/hr**	**~460 kg/hr**	**~60 kg/hr**	**~460 kg/hr**
ESP only	10	n.a.	n.a.	n.a.	n.a.
FF only	29	n.a.	n.a.	n.a.	n.a.
Activated carbon injection + FF	50-90+	56.5	127.0	89.0	84.0
Polishing wet scrubber + FF	85	400.0	400.0	100.0	100.0

Abbreviations:
ESP - Electrostatic precipitator
FF - Fabric filter (baghouse)
FGD - Flue gas desulfurization
SDA - Spray dryer absorber
MWh - Megawatt-hours
MWC - Municipal waste combustor
MWI - Medical waste incinerator

8.5.2 Costs of chlor-alkali conversion

714. Pirrone *et al*. (2001) and others (Lindley 1997, Fauh 1991, etc.) have noted that the membrane chlor-alkali process is more energy efficient than the mercury cell process. They have also pointed out that conversion from the mercury cell to the membrane process is possible utilizing some of the existing equipment. While keeping in mind the previous remark that the decision to convert from mercury cells to another process is not a purely economic decision, one may look more closely at the costs involved.

715. Euro Chlor, the association representing the European chlor-alkali industry, has estimated that conversion of a typical plant from mercury electrolysis to membrane electrolysis would cost about $US 500 per metric ton of chlorine capacity. US EPA (1997) produced estimates for conversion that are roughly in line with those of Euro Chlor. Lindley (1997) also estimated conversion costs for a typical West European chlor-alkali plant at the euro equivalent of about $US 500 per metric ton of chlorine capacity. Harris (2001) has estimated conversion costs in the range of $US 400-700 per metric ton of chlorine capacity, and operating cost savings in the range of $30-50 per metric ton of chlorine capacity, noting that the economic attractiveness of any given project will be highly dependent on its special circumstances, but concluding that conversion will be economically attractive only in exceptional cases.

716. It is informative to compare these high conversion costs with the striking reductions in mercury emissions (96 percent since 1977) in European, and in mercury consumption (75 percent since 1995) in the US chlor-alkali industries in recent years (see chapter 7) through a variety of equipment upgrades and improvements in housekeeping practices – at costs at least 100 times lower per gram of mercury prevented from entering the environment. In this perspective, the highest near-term priority, and the greatest reduction in mercury releases for a very modest investment, might be to extend this experience and these techniques as rapidly as possible to all other mercury-cell chlor-alkali plants around the world. Despite the reductions achieved by such measures, significant consumption of mercury must still be anticipated until conversion to mercury free technology takes place. The (US) Chlorine Institute's and (European) Euro Chlor's detailed guidelines on preventing air emissions and other releases should serve to indicate the most rapid and least expensive way forward.

8.5.3 Costs of dealing with releases from artisanal gold mining

717. Previously a long list of measures was presented for reducing releases and exposures from artisanal gold mining practices. Depending on the measures one wishes to pursue, the range of related costs is vast. Therefore the establishment of a typical amalgamation center was selected as an example of "extreme" measures that may have to be taken in order to really have a profound effect on a large number of miners in a given region.

718. According to UNIDO (1997) the cost of establishing a UNECA-type center (see section 8.3.6) depends on the process to be adopted (amalgamation with special plates and/or NaCl electrolytic leaching process), infrastructure needs, power supply, civil works, material costs, transportation and labor costs of the mining region. The estimated typical investment and operating costs are summarized in table 8.15.

Non-mercury processes for recovering gold

An **electrolytic process** to leach gold has also been developed by CETEM (UNIDO, 1997) - Center of Mineral Technology, Rio de Janeiro and tested in a pilot plant in the Tapajós region, Brazil. This process has the potential to replace amalgamation of gravity concentrates. Material with 1 ppm Au was mixed with sodium chloride (1 Mol/l), which is transformed by electrolysis into a mixture of sodium hypochorite-chlorate. More than 95 percent of the gold dissolves within 4 hours and is collected on a graphite cathode. The solution is always recycled minimizing effluent discharge. The NaCl and energy consumptions are 100 kg/metric ton of ore and 170 kwh/kg of Au respectively. Plastic leaching tanks are used, reducing investment cost. So the process is relatively uncomplicated and inexpensive with the potential for use. The main drawback of course, is the need for trained personnel to control operating variables (pH, current density, etc).

The UNECA-type Processing Center is suitable for installation in mining villages or in any central area to facilitate transportation of gravity concentrates. Gold recovery is actually improved and mercury exposure to the operators is insignificant. For a miner who takes his concentrate to a Processing Center, there is the additional benefit of reducing costs in his own processing plant. These Centers play an important role in bringing information about mercurialism caused by mercury vapour and contaminated fish ingestion. Miners can be given brochures and additional instructions while they wait for the processing of their concentrates. The Centers can provide advice for miners on how to improve their production and can provide a meeting place for other purposes of education and organization.

Another option has been reported from South Africa (MMSD, 2002), where the government's mineral technology research body, Mintek, has developed the new Minataur process. This involves treating the ore with hydrochloric acid in the presence of sodium hypochlorite and then using sodium metabisulphate or oxalic acid to precipitate the gold out as a concentrate that is 99.5% fine gold powder.

Table 8.15 Estimated capital cost of a UNECA Center (based on UNIDO, 1997)

Estimated fixed capital costs (equipment)	**US$**
Amalgamation-plates (2 sluices of eight 30x40 cm plates each in metallic frame)	20,000
Fume hoods, air filters, scrubbers, retorts, melting furnace	39,000
Electrolytic leaching system incl. filters and activated charcoal column	60,000
Other	10,000
Subtotal fixed capital costs	**129,000**
Estimated variable capital costs	
Civil construction + water works	20,000
Mechanical + electrical	10,000
Personnel costs (Engineer, laborers, expenses, training)	88,000
Subtotal variable capital costs	**118,000**
TOTAL CAPITAL COSTS	**247,000**

719. The costs presented in table 8.15 do not include power supply, which must be available on site, or the cost of land, which could be arranged by the local community. The total capital investment of nearly US$ 250,000 is high, but it can be greatly reduced after the installation of the first center as many local personnel can be trained, and as technology is transferred to local technical people who can be in charge of building other centers.

720. In addition to capital cost, one must consider operating cost, as presented in table 8.16.

Table 8.16 Estimated monthly operating costs for a UNECA Center (based on UNIDO, 1997)

Estimated operating costs	**US$/month**
• Labor & security personnel	4,900
• Electricity & gas	1,500
• Supplies & maintenance	6,000
• Mercury monitoring	500
• Proper disposal, etc.	2,000
TOTAL	**14,900**

721. As in Venezuela, the UNECA Center can charge US$ 1/kg of concentrate processed, thereby deriving an income of about US$ 10,000/month. This nearly covers the operating cost. The UNECA Centers are also decontamination centers. Using the electrolytic process, residual mercury and gold can be extracted from dredged "hot spots". Likewise, tailings produced by individual miners who continue to amalgamate their concentrates can also be treated in the Center. As the gold content in amalgamation tailings is high, as observed in Venezuela, the decontamination step might be profitably conducted by private companies. The Center should provide a safe landfill for the decontaminated residues.

8.5.4 Other costs and benefits

A. Human health benefits

722. The human health benefits associated with reductions of mercury in the biosphere have been addressed in detail in chapter 4.

B. Economic costs of mercury use, especially in products

723. The purely economic costs of dealing with the mercury in our products and our surroundings are considerable, but describing them in detail is not within the scope of this assessment. Nonetheless, several examples are worth mentioning, such as: cost of collecting separately mercury containing products; cost of recycling or acceptable disposal, whether to a special landfill or to a hazardous waste incinerator; cost of generating and enforcing legislation to deal with mercury in every sector of the economy; cost of tracking movements of mercury waste; cost of the extensive programmes in various countries (such as around the Great Lakes region of the USA and Canada) to significantly reduce mercury releases; cost of pursuing automobile companies to replace mercury switches; cost of special controls on municipal waste incinerators to remove mercury from the flue gases, etc. All of these examples represent costs to the local, regional and world economies that remain because mercury remains reasonably free to move through the economy.

C. Ecological and welfare benefits of reducing mercury pollution

724. As an example of a great variety of benefits that are often given little notice, it is instructive to consider in some detail the ecological and welfare benefits of reducing mercury pollution. As noted in US EPA (1997), mercury can adversely affect **ecological systems** at various levels: at the individual organism level, at the population level, and at the community or ecosystem level. While the effects on populations, communities, and ecosystems are of primary concern for most species, individual effects are also of interest because they may cause effects at higher levels of the ecological system, especially effects in vulnerable or reduced populations such as threatened and endangered species, raptors, and furbearers.

725. Likewise, there is a broad range of **cultural and welfare benefits** associated with reductions in the global mercury load. US EPA (1997) noted that the top three social and economic damages to native peoples were (1) diminishment of cultural and religious values; (2) damage to subsistence activities (e.g., subsistence fishing); and (3) damage to natural resources in commercial use. Fishing often plays a

role in all three of these areas. With respect to cultural values, for example, the Wisconsin Native Americans have built centuries-old traditions around spearing fish and sharing the catch. Growing concerns about limiting fish consumption and limiting the locations where fish may be caught seriously affect the Tribe's traditions (US EPA 1997).

726. The Arkansas Game and Fish Commission attempted to quantify fishing-related monetary losses due to mercury contamination as of 1994. Although the Commission has not published its findings (Armstrong 1994), it estimated a loss of fishing expenditures due to mercury fish consumption advisories of over $US 5 million from 1991 to 1992. This estimate was derived from decreased purchases of fishing license in counties where mercury advisories were issued, multiplied by the average number of trips an angler takes per year, and by the average per-trip expenditures. Changes in expenditures represent changes in welfare (US EPA 1997).

727. Other than the work cited above, little work has been done to quantify the value of most of these ecological and welfare benefits, which will vary greatly in any case from one region to another. Therefore, the summary provided in table 8.17 below is presented without any attempt at quantification.

Table 8.17 Summary of typical ecological/welfare benefits and the potential adverse effect on them from mercury pollution (from US EPA, 1997)

Ecological/welfare benefit or use category	**Adverse effect of mercury pollution**
Recreational Fishing	• Reduced number of fishing trips • Lost value per trip due to fish advisory • Lost value due to inability to consume fish
Commercial Fishing	• Lost value of fish exceeding maximum allowable concentration • Reduced demand for all fish due to perceived health threat
Subsistence fishing	• Lost value of fish no longer consumed • Lost nutritional value • Lost cultural value associated with subsistence fishing activity
Timber	• Reduced growth/productivity of commercial forests
Forest recreational activities	• Reduced number and/or value of recreational activities due to reduced quality of surrounding plants
Agricultural	• Reduced growth/productivity of crops
Recreational/Commercial Hunting/Trapping	• Reduced or lost commercial value of target species • Reduced value of recreational hunting/trapping activity with reduced population of target species
Recreational bird hunting	• Reduced number of trips for target species • Lost value per trip due to reduction in target species
Bird/animal viewing	• Reduced value of recreational activities with lower probability of viewing target species
Cultural/religious value	• Reduced cultural/religious value due to fish advisories, not associated with use
Existence value of specific species, including option value, bequest value, scarcity value, in addition to existence value	• Adverse effects on specific species (individuals and populations)
Biodiversity	• Adverse effects on biodiversity
Stewardship value, including moral obligation to reduce harm to ecological resources	• Adverse effects on specific species or in general
Preservation of ecosystem health, including maintaining the integrity of predator/prey relationships	• Adverse effects on ecosystem health

9 Initiatives for controlling releases and limiting use and exposure

9.1 Overview

728. Chapter 9 responds to the request of the UNEP Governing Council to describe ongoing actions and compile information about future plans at the national, sub-regional or regional levels for controlling releases, and limiting use and exposures, including waste management practices. It is divided into 4 sections, covering:

- National initiatives for controlling releases and limiting use of and exposure to mercury;
- International agreements and instruments and their relevance to mercury;
- International organizations and programmes and their relevance to mercury;
- Sub-regional and regional initiatives and their relevance to mercury.

729. The first section on national initiatives examines the issue from several angles. First, a general overview of the main types of measures that have been implemented and a brief status of their implementation is given. Thereafter, a more detailed description of the various types of actions used to reduce or eliminate specific uses in products or releases from point sources are described and concrete examples from different countries that have taken action are given. Finally, three national examples of coordinated approaches to obtaining a set goal of reducing or eliminating uses and releases of mercury, involving extensive national regulation of the use and handling of mercury in the society are described in detail, together with an indication of the reductions in mercury consumption and use that have been obtained through these initiatives.

730. The last 3 sections provide a catalogue of information on international agreements and instruments, international organizations and programmes and sub-regional and regional initiatives and their relevance to mercury. Only some of these initiatives are legally binding on participating countries, however, these initiatives are valuable supplements to national initiatives, and facilitate awareness-raising, information exchange and the setting of reduction goals.

731. It should be noted that, as a supplement to this chapter, a more detailed compilation of national initiatives, including legislation, in each individual country is contained in an appendix to this report, entitled “Overview of existing and future national actions, including legislation, relevant to mercury”. The Appendix is published in a separate document. The information compiled therein has been extracted from the national submissions received under this project and is organized along the same lines as this section, thus making it possible to identify additional examples for most of the types of measures described in this section.

732. The chapter shows that the environmental authorities in many countries consider mercury to be a high-priority substance with recognised adverse impacts. They are aware of the potential problems caused by use and release of mercury and mercury compounds, and therefore have found it necessary to protect health and the environment from its adverse impacts by implementing measures at national level to limit or prevent certain uses and releases. However, it is also clear that because of mercury’s persistence in the environment and the fact that it is transported over long distances by air and water, crossing borders and often accumulating in the food chain far from it’s original point of release, a number of countries have concluded that national measures are not fully sufficient. These countries have initiated measures at regional, sub-regional and international level to identify common reduction goals and ensure coordinated implementation.

733. With regard to the information contained in this chapter, if no specific reference is mentioned, the information on national initiatives and regulatory measures is based on that found in the national

submissions to this project. Information on international, sub-regional and regional initiatives is based, in addition to that found in the individual submissions to this project, on information available in the public websites of the organizations or initiatives described.

9.2 National initiatives

9.2.1 Overview of existing national initiatives

734. Table 9.1 gives an overview of types of implemented measures of importance to management and control of mercury, as related to its production and use life cycle, and an indication of their status of implementation. As can be seen from the table, existing types of measures cover most phases in the lifecycle of mercury products and processes. See also chapter 8 for additional information on prevention and control technologies for reducing mercury releases.

9.2.2 Common features of existing national initiatives

735. A number of countries have implemented national initiatives and actions, including legislation, to manage and control releases and limit use and exposures of mercury within their territories.

736. Legislation provides an impetus and a framework for the safe management of chemicals, including mercury and mercury compounds. It may take the form of laws, decrees, orders, regulations, rules, standards, norms and similar written statements of national policy and requirements for behaviour. National legislation is often composed of one or more general or “umbrella” laws, implemented by specific subsidiary regulations. Countries rarely have a single law to cover chemicals, including mercury, instead separate pieces of legislation and separate ministries are commonly involved, highlighting the need for cooperation between government ministries in the development, implementation and enforcement of legislation on chemicals.

737. Although legislation is the key components of most initiatives, safe management of mercury may also include efforts to reduce the volume of mercury in use by developing and introducing safer alternatives and cleaner technology. It may also include other national measures, such as the use of subsidies to support substitution efforts and voluntary agreements with industry or users of mercury.

738. Such initiatives have stimulated significant reductions in mercury consumption in a number of countries, and corresponding reductions of releases have been attained. To date, available overviews of national initiatives, including legislation, addressing mercury have been limited mainly to countries within the OECD. The national information submitted to the Global Mercury Assessment from all regions of the world has cast some new light on this issue.

739. The overall aims of existing initiatives on mercury are to reduce/prevent the release of mercury to the environment and avoid direct/indirect impacts on human health and the environment. Many common features can be found among the countries that have submitted information to this project. The initiatives can generally be grouped as follows:

A. Environmental quality standards, specifying maximum acceptable mercury concentrations for different media such as drinking water, surface waters, air, soil and for foodstuffs such as fish;

B. Environmental source actions and regulations that control mercury releases into the environment, including limits on air and water point sources and promoting use of best available technologies and waste treatment and waste disposal restrictions;

C. Product control actions and regulations for mercury-containing products, such as batteries, cosmetics, dental amalgams, lighting, paints/pigments, pesticides, pharmaceuticals, etc.;

D. Other standards, actions and programmes, such as regulations on exposures to mercury in the workplace, requirements for information and reporting on use and releases of mercury in industry, fish consumption advisories and consumer safety measures.

Table 9.1 Overview of implemented measures of importance to mercury, as related to its production and use life cycle, and an indication of status of implementation, based on information submitted for this report.

TYPE AND AIM OF MEASURE		STATE OF IMPLEMENTATION
Production and use phases of life cycle		
POINT SOURCES	Prevent or limit the intentional use of mercury in processes	General bans implemented in very few countries
	Prevent or limit mercury from industrial processes (such as chlor-alkali and metallurgic industry) from being released directly to the environment	Implemented in many countries, especially OECD countries
	Apply emission control technologies to limit emissions of mercury from combustion of fossil fuels and processing of mineral materials	Implemented in some OECD countries
	Prevent or limit the release of mercury from processes to the wastewater treatment system	Implemented in some OECD countries
	Prevent or limit use of obsolete technology and/or require use of best available technology to reduce or prevent mercury releases	Implemented in some countries, especially OECD countries
PRODUCTS	Prevent or limit products containing mercury from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as batteries, lighting, clinical thermometers
	Prevent products containing mercury from being exported	Only implemented in a few countries
	Prevent or limit the use of already purchased mercury and mercury-containing products	Only implemented in a few countries
	Limit the allowable content of mercury present as impurities in high-volume materials	Only implemented in a few countries
	Limit the allowed contents of mercury in commercial foodstuffs, particularly fish, and provide guidance (based on same or other limits values) regarding consumption of contaminated fish	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries.
Disposal phase of life cycle		
Prevent mercury in products and process waste from being released directly to the environment, by efficient waste collection		Implemented in many countries, especially OECD countries
Prevent mercury in products and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment		Implemented in many countries, especially OECD countries
Prevent or limit mercury releases to the environment from treatment of household waste, hazardous waste and medical waste by emission control technologies		Implemented or implementation ongoing in some countries, especially OECD countries.
Set limit values for allowable mercury contents in sewage sludge spread on agricultural land		Implemented in a number of countries
Restrict the use of solid incineration residues in road-building, construction and other applications		Implemented in some OECD countries
Prevent the re-marketing of used, recycled mercury		Only implemented in a few countries

740. As far as can be seen, no country has so far developed one comprehensive legislation covering the lifecycle of mercury. Many countries have a number of actions and regulations covering specific uses or releases - in a few of these countries the implemented actions in total cover the full lifecycle of mercury. Often, legislation related to production, marketing and use of mercury and mercury-containing products are specific to mercury, whereas legislation on releases and the disposal of wastes are often more general, and include other heavy metals and specific inorganic and organic pollutants.

741. It should be noted that considerable variation exists between countries and regions with regard to the types and numbers of uses and releases controlled. Some countries have reported that they have no legislation covering mercury at all, while for example Sweden has a number of regulations which in total aim to phase out, as far as possible, most uses of mercury in the country by 2003 (see section 9.2.4 SWEDEN for details). It must also be kept in mind that the existence or not of initiatives and legislation on mercury in a country must be seen in connection with the use and release patterns of that country and the need to address specific risks to health and the environment posed by these uses or releases.

9.2.3 Common types of national initiatives

742. This section contains a summary of some of the most common types of initiatives implemented within each of the 4 groups described above. It should be noted that the descriptions are general and that some countries might have even more restrictive measures in place.

743. A more detailed compilation of national initiatives, including legislation, in each individual country is contained in an appendix to this report, entitled “Overview of existing and future national actions, including legislation, relevant to mercury”. The Appendix is published in a separate document. The information compiled therein has been extracted from the national submissions received from countries under this project and is organized along the same lines as this section, thus making it possible to identify additional examples for most of the types of measures described in this section.

A. Environmental media standards, specifying a maximum acceptable mercury concentration for different media

744. **Water, air and soil -** In order to limit the general population’s exposure to mercury and mercury compounds, a number of countries have established standards setting maximum acceptable concentration limits for mercury in a number of different media, such as water (drinking water, surface waters, water to be used for irrigation, water for livestock, etc.), air (ambient air, indoor air, etc.) and soil. In contrast to source related regulations, which apply directly to individual sources, these environmental standards have an indirect effect on individual sources and releases. Often, they form the basis for regulation of individual sources. The limits vary from country to country, examples can be found in the Appendix mentioned above.

745. It should also be noted that WHO has developed guidelines for drinking water quality (WHO, 1993) and air quality (WHO, 1999) that provide a basis for protecting public health from adverse effects of air pollution and for eliminating, or reducing to a minimum, those contaminants that are known to be hazardous to human health and well being. Both of these guidelines also cover mercury. The guidelines provide background information for setting national quality standards. In moving from guidelines to standards, prevailing exposure levels and environmental, social, economic and cultural conditions in the country should be taken into account. In certain circumstances there may be valid reasons to pursue policies that will result in pollutant concentrations set above or below the guideline values.

746. **Foodstuffs -** In order to limit the general populations exposure to mercury and mercury compounds, a number of countries have established standards setting maximum acceptable concentration limits in a number of foodstuffs. The most common seems to be for fish and shellfish, although India also has reported limits for vegetables and milk. The standards vary from country to country, examples can be found in the Appendix mentioned above. See also section 4.2.1 for mercury limits in fish.

747. The FAO/WHO Codex Alimentarius Commission has also set guideline levels for methylmercury in fish, as follows:
All fish except predatory fish: 0.5 mg/kg;
Predatory fish (such as shark, swordfish, tuna, pike and others): 1 mg/kg.
Where the guideline levels are exceeded, governments are recommended to decide whether and under what circumstances, the food should be distributed within their territory of jurisdiction and what recommendations, if any, should be given as regards restrictions on consumption, especially by vulnerable groups such as pregnant women. (Codex Alimentarius, 1991)

748. **Consumption –** Some countries have issued consumption advisories with regard to foodstuffs that are known to contain high mercury concentrations. For example, Australia, Canada, Norway, Sweden, the United Kingdom and the United States have issued fish advisories to consumers containing recommendations on how to reduce exposures to mercury and other toxic chemicals through consumption of fish. Often, consumer groups especially at risk, such as pregnant women and women of child-bearing age, are covered by such advisories.

749. The US Food and Drug Administration has advised women of childbearing age to limit their consumption of shark, swordfish, tilefish and king mackerel based on methylmercury content. States, tribes and territories are responsible for issuing fish consumption advice for locally caught fish; many state health departments use 0.5 ppm methylmercury as a trigger for such advice. The authorities of Sweden recommend pregnant or lactating women and women planning to have children soon, not to consume species such as pike, perch, pikeperch, burbot and eel because of risk for increased methylmercury exposure. Since fish consumption in general is encouraged, the general population is encouraged to consume these species, but not more often than once a week on average. Another example is the Food Standards Agency in the United Kingdom, which in May 2002 advised that pregnant women, women who intend to become pregnant, infants and children under 16 years of age should avoid eating shark, swordfish and marlin. Occasional consumption of shark, swordfish or marlin as part of a balanced diet by any other adults is unlikely to result in harmful effects, however, on a precautionary basis, they were advised against eating more than one portion a week of either shark, swordfish or marlin.

750. **Exposure -** A tool used to assess the risk of mercury to the general population is dose-response assessments. The US EPA has for example established a “Reference dose” for methylmercury of 0.1 µg/kg body weight per day. The reference dose is an estimate of daily exposure to the human population that is likely to be without an appreciable risk of adverse effects during a lifetime. Canada recently set a temporary or provisional Tolerable Daily Intake (TDI) for mercury of 0.2 µg/kg body weight per day for women of child-bearing age and young children, based on health considerations for pre-natal exposure and during the period of early central nervous system development in childhood.

751. Also, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a provisional tolerable weekly intake (PTWI) for methylmercury of 3.3 µg/kg body weight per week. The tolerable intake represents the maximum acceptable level of a contaminant in the diet; the goal should be to limit exposure to the maximum feasible extent, consistent with the PTWI. (FAO/WHO, 1999)

B. Environmental source controls/regulations that control mercury releases into the environment

752. **Emission limits for air and water point sources -** Many countries have legislation prescribing maximum allowable releases of mercury (and other pollutants) from various types of industrial and other facilities (point sources) to air, water and soil/groundwater. Such legislation might require use of exhaust gas filters, wastewater treatment and handling of solid residues similar to that of household waste incinerators. Also, legislation has been implemented preventing or limiting the release of mercury from processes to the wastewater system in order to limit releases to the water recipient, to permit the use of the sludge as fertiliser on agricultural land and to reduce treatment costs. Legislation limiting emissions of a number of pollutants from combustion of fossil fuels is also common in a number of countries, however, legislation covering mercury emissions from coal-fired power plants (a major source) appears to be rare.

753. **Best available techniques**[28] **-** For certain types of potentially heavily polluting industries, for example the chlor-alkali industry, legislation might not be limited to setting emission limits to air, water and soil, but might also require the use of specific, less polluting production methods and pollution prevention technologies or “best available techniques".

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[28] As contrasted with “best available technologies,” “best available techniques” (BAT) is a wider term that includes best available technologies but also considers other techniques such as process change, etc. BAT is increasingly used in regional (e.g. EU) and global (e.g. the Stockholm Convention and the Aarhus Protocol to the LRTAP Convention) forums, where it is well defined and well accepted.

754. For example, under the Clean Air Act Amendments of 1990 the US EPA regulates Hazardous Air Pollutant Emissions by industrial source categories using Maximum Achievable Control Technology (MACT) standards for each "major source" in any source category. A MACT standard is defined based on an analysis of existing control technology among the best-controlled sources in a given source category. Another example is the European Community Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. It requires the application of best available techniques (BAT) to prevent or reduce pollution of the air, water and land from a number of industrial activities in order to achieve a high level of protection of the environment taken as a whole. As part of implementation of the Directive, reference documents on best available techniques (BREF) are developed for different sectors. See section 9.2.4 EUROPEAN COMMUNITY for more details.

755. **Waste incineration -** Legislation prescribing maximum allowable releases of a number of pollutants, including mercury, from incineration facilities for household and hazardous wastes respectively, to the atmosphere and wastewater, as well as specifications on the deposit of solid incineration residues exist in a number of countries. Indirectly, such legislation might dictate the use of a limited number of emission control technologies, which are capable of complying with the emission requirements. For example, some countries have extensive exhaust gas filtering on all waste incineration facilities (hazardous, medical and household waste), holding back a major part of the otherwise emitted mercury.

756. **Use of solid incineration residues -** Legislation is also found prescribing maximum allowable concentrations of mercury, often together with other pollutants, in ashes and slag from waste incineration and fossil fuel combustion that can be used for construction purposes (roads, etc.), as well as in wastewater sludge to be used as fertiliser on agricultural land.

757. For example, Belarus reports that accounting, storage conditions, collection and utilization of mercury-containing wastes are governed by the normative document “Regulations on the procedure of accounting, storage, collection of mercury and mercury-containing wastes”, approved by the Ministry of Economy, Ministry of Natural Resources and Environment Protection, Ministry of Public Health and Ministry for Extreme Situations. In Switzerland, for example, the Ordinance on Substances (1986) sets a maximum level of 5 mg/kg of mercury in sewage sludge (OECD, 1994), while in Finland sludge from wastewater treatment plants may be used as fertilizers in agriculture only if the concentration of mercury in the pre-treated sludge is under 1 mg/kg dry weight.

758. **Waste treatment –** In a number of countries, especially those within the OECD, legislation exists prescribing separate collection and waste treatment of products and process waste containing mercury – for example batteries, fluorescent light tubes and dental amalgam filter residues. The aim of such legislation is to prevent or minimise the diffuse spreading of mercury-containing products and prevent dumping of process waste in the environment, as well as limiting the amounts of mercury-containing waste in the general household waste stream (where it causes significant mercury emissions and increases waste treatment costs).

C. Product control regulations for mercury-containing products

759. Regulatory measures limiting or preventing a large range of products containing mercury from being marketed nationally, and in some cases also prohibiting import and export, have been implemented in a large number of countries through the world.

760. **Batteries –** As alternatives have become increasingly available, many countries have in recent years implemented legislation setting permissible levels of mercury in batteries and accumulators, effectively prohibiting use of mercury oxide batteries and severely limiting the use of mercury-containing button cell batteries. Such legislation might also require the separate collection of mercury containing batteries.

761. In Switzerland, for example, the Ordinance relating to Environmentally Hazardous Substances, amended in 1998 and which also deals with batteries, limits the mercury and cadmium contents of batteries sold in articles of any kind to < 0.001 percent (w/w). Exceptions require special approval. It also defines consumers’ duty to return used batteries and traders’ duty to accept returned batteries of all

kinds. In addition, the annex defines producers' obligation to pay a fee to the respective organization, when commercializing batteries and battery-containing articles. This fee covers the cost of adequate waste treatment.

762. In Mauritius, mercury batteries are no longer used and have been replaced by nickel/cadmium batteries. A national campaign was launched to collect all mercury cells a few years ago. There is, however, still a problem with disposal/recycling. There is an ongoing awareness programme for the collection of mercury button cells until a policy decision is taken regarding their safe disposal.

763. Some countries have dealt with the issue of mercury in batteries through voluntary measures. The Canadian Household Battery Manufacturers' Association eliminated the deliberate addition of mercury to household alkaline, zinc-carbon and zinc-chloride batteries as of January 1997. The only major type of mercury-containing battery available in Canada may be mercury-oxide batteries.

764. **Cosmetics –** Legislation also exists limiting or prohibiting mercury in cosmetic products. An example is European Community Directive 76/768/EEU (and its amendments 2000/6/EU and 2000/11/EC) on the approximation of the laws of the member states relating to cosmetic products. This Directive stipulates that mercury and its compounds may not be present as ingredients in cosmetics, including soaps, lotions, shampoos, skin bleaching products etc. (except for phenyl mercuric salts for conservation of eye make-up and products for removal of eye-make-up in concentrations not exceeding 0.007 percent weight to weight).

765. In Cameroon, an inter-ministerial Order bans the importation, marketing and use of cosmetic products containing more than 2 percent mercury. Under this order, twelve soaps and thirteen creams were banned.

766. **Dental amalgam –** A number of countries have put in place measures to reduce or even phase out the use of mercury in the dental sector. In addition to the use of amalgam separators to substantially reduce the amount of mercury discharges through wastewater from dental clinics (combined with appropriate service to maintain the effectiveness of these systems), some countries are also promoting the substitution of mercury-containing amalgam fillings, especially among sensitive populations including pregnant women, children and those with impaired kidney functions.

767. Denmark and Sweden are perhaps among those countries that have gone the farthest in attempting to eliminate the use of mercury-containing amalgam. The Swedish Government's overall goal to phase-out mercury also includes dental amalgam. In Sweden the consumption of mercury for dental use has decreased significantly after a policy decision by the Parliament in 1994 to phase out the use of dental amalgam. Up to now dental amalgam has been subject primarily by voluntary phasing out measures. In Denmark, dental amalgam is allowed only in molar teeth, where the filling is worn, but the Government is ready to ban the remaining use of dental amalgam, whenever the Danish National Board of Health is satisfied that the non-mercury alternatives have full substitution capabilities. Currently, Norway is developing a directive on the use of dental filling materials, which will encourage dentists to reduce the use of amalgam as much as possible. The directive is expected to take effect 1 January 2003.

768. In New Zealand, a "Practice guideline - controlling dental amalgam waste and wastewater discharges" has been adopted, describing a code of practice on the use, storage, collection and disposal of mercury in New Zealand dental surgeries. It recommends that amalgam scrap should be collected, stored and sent for recycling or for disposal at an approved landfill when collection for recycling is not available. Amalgam scrap should be stored under water in an airtight container to reduce mercury vapour levels. Also, amalgam scrap and contaminated particulate amalgam waste should not be disposed of in any medical waste to be incinerated. Dental surgeries should use systems to reduce amalgam discharge to wastewater - in regions where reductions in total mercury discharge to wastewater are required by territorial local authorities, amalgam separators should be installed and serviced appropriately to maintain the effectiveness of these systems. In addition, the Ministry of Health commissioned an extensive review of dental amalgam and human health in early 1997 and found that no new scientific evidence had emerged to indicate present or future public health problems associated with the use of amal-

gam in dental fillings. It has issued precautionary advice for dentists and pregnant women. It recommends that amalgam still be used but with informed consent from patients and is advising dentists to avoid using or removing any tooth filling material in pregnant women, where clinically reasonable.

769. **Electric equipment –** Within the European Community, a proposal for a new directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment involving mercury is currently under discussion in the European Council and Parliament. The proposed Directive requires the substitution of mercury in electrical and electronic equipment by 2008. In the proposal, switches and other electrical control devices are included, whereas fluorescent lamps up to certain limits (10 mg mercury/lamp) and certain other mercury-containing lamps are exempted. In Sweden, mercury-containing measuring and control instruments, as well as electric and electronic components are banned for manufacture and sale since 1993.

770. **Lighting –** Also with regards to lighting containing mercury there are national initiatives ongoing both to reduce the amount of mercury used in such products, to recycle the mercury contained in spent products and to find acceptable non-mercury substitutes for such products. See also section 8.2 on substitution.

771. In Trinidad and Tobago, a certain replacement of devices that contain mercury has taken place. Currently, a major manufacturer of lighting fixtures has switched to low-mercury fluorescent lamps containing up to 3 mg mercury per lamp. The lamps are classified as non-hazardous waste in the United States, and can be disposed of in municipal landfills. These low-mercury fluorescent lamps are available in Trinidad and Tobago, and their use is one means of controlling mercury.

772. The Canada-wide Standard for mercury-containing lamps takes a pollution prevention approach by reducing the mercury content of lamps sold in Canada. The standard is a 70 percent reduction by 2005 from a 1990 baseline, and an 80 percent reduction by 2010 in the average content of mercury in all mercury-containing lamps sold in Canada. The average mercury content in fluorescent lamps has fallen from 48.2 mg in 1985 to 27 mg in 1995, with an industry target to further reduce mercury content to 15 mg.

773. Belarus reports that there are three organizations engaged in rendering spent mercury-containing lamps harmless and one that renders them harmless and removes the mercury from mercury-containing wastes. The total capacity of all four organizations is about 3.5 million lamps per year and 10 metric tons of mercury-containing wastes. About 1.2 million spent mercury-containing lamps are disposed of each year.

774. Switzerland reports that there is still very significant use of mercury-containing fluorescent lamps, however, there are also an increased recycling rate. The Swiss heavy metal recycling organization is specialized in treating batteries and other mercury-containing waste. Between 1999 and mid-2001, it took in a yearly average of 154 metric tons of mercury-containing waste, of this ~32 metric tons of broken fluorescent lamps.

775. In Denmark, mercury-containing products are generally banned, however, special light sources (fluorescent tubes, including low-energy bulbs, for analysis apparatus and for graphic operations) are allowed until further notice, since satisfactory substitutes are not yet available.

776. **Packaging and packaging waste –** A few countries have in recent years set limits on the content of some heavy metals, including mercury, in packaging materials, in order to limit the flow of mercury into the waste stream. The EU packaging directive is, among others, aimed at promoting packaging materials recycling/energy recovery and limiting the flow of heavy metals to waste treatment and resulting environmental releases. The Directive sets limits on allowed concentrations of mercury present as impurities in packaging materials. See section 9.2.4 EUROPEAN COMMUNITY for details.

777. **Paints/pigments –** Mercury was previously used extensively as a biocide in paints, however, such use has now been substantially reduced or eliminated in a large number of countries. For example,

Mauritius reports that mercury is no longer used in paints. In Trinidad and Tobago, mercury was used in paints as a fungicide, but today on the whole, mercury has been replaced by other biocides.

778. In Costa Rica, the regulation on the content of lead and mercury in paints sets a maximum limit of mercury in paints to 0,005 percent. Also, Thailand reports that less than 25 percent of the factories in Thailand still use mercury as an additive in the process and in quantities of not more than 0.5 percent by total weight. Some paint industries in Thailand have no mercury involved in their processes since 1991, and are certified “green label”.

779. **Pesticides -** Sale and use of pesticides containing mercury for plant protection purposes and as a seed dressing have been severely restricted or prohibited/discontinued in a large number of countries throughout the world, although certain limited uses remain allowed in some countries. Lesotho has reported that two mercury-based pesticides, used as a dip for potatoes and as a seed dressing for seed-borne diseases in grain crops, have been discontinued. In Colombia, registration of fungicides for agricultural use based on mercury compounds was cancelled. Presently, no registration has been granted for any mercury-based pesticide.

780. In Australia, two products containing mercury are registered for use on sugarcane and horses. One liquid fungicide product contains 120 g/l of mercury as methoxy-ethyl mercuric chloride to control pineapple disease in sugarcane setts, which are dipped in or sprayed with a dilute solution before planting. Another product for horses contains mercuric chloride at 3 g/l and is used topically to treat leg injuries, soreness and musculoskeletal conditions.

781. **Thermometers –** Mercury-containing thermometers is a product consumers all over the world are familiar with. In Sweden, the import, professional manufacture and sale of clinical mercury thermometers were prohibited from 1 January 1992. Professional manufacture, import and sale of thermometers, level switches, pressure switches, thermostats, relays, electrical contacts and other measuring instruments has been banned since 1993. A few exemptions still exist, mainly for spare parts, however, a time-schedule for phase-out is stipulated for each exemption. In addition, in order to promote collection of mercury thermometers, economic incentives have been used to persuade households to turn in their mercury thermometers. In Denmark, there is a general ban on sale of mercury containing thermometers. Exemptions from this ban are primary EU approved thermometers.

782. **Thermostats** - As a voluntary measure, the industry-funded Thermostat Recycling Corporation (TRC) launched a programme in 1997 to recycle mercury-switch thermostats in nine states. It has since been expanded to 48 states in the USA, and in 2001 collected 48,215 thermostats and 402 pounds of mercury, for a total of more than 120,000 thermostats and 1,000 pounds of mercury since the programme's inception.

783. **Vehicles –** European Community Directive 2000/53/EC of 18 September 2000 on end-of life vehicles, lays down measures that aim at prevention of waste from vehicles and promotion of reuse, recycling and other forms of recovery of end-of life vehicles and their components so as to reduce the disposal of waste, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles. According to Article 4 of this Directive, mercury is restricted in materials and components of vehicles. Materials and components of vehicles put on the market after 1 July 2003 shall not contain mercury.

784. In the United States, the use of mercury-containing light applications in vehicles is gradually being phased out through voluntary initiatives by the auto manufacturing industry. See section 9.2.4 UNITED STATES for details.

785. **Pharmaceuticals - Vaccines -** Thiomersal (also known as thimerisol, thimerosal or mercurothiolate) is a mercury-containing compound used in trace amounts to prevent bacteria and other organisms from contaminating vaccines, especially in opened multi-dose vials. According to WHO, none of the "live" vaccines, including measles, MMR, oral polio, yellow fever, and BCG contain thiomersal. Many of the other vaccines in single-dose vials do not contain thiomersal either. However,

multi-dose formulations of triple vaccine (DTP), diphtheria and tetanus toxoids (DT and Td), tetanus toxoid (TT) and some hepatitis B vaccines on the global market contain thiomersal. According to WHO, there are other chemicals such as 2-phenoxy-ethanol used as vaccine preservatives, however, thiomersal is currently the best alternative. (WHO, 2001) (For more information, see http://www.who.int/vaccines-surveillance/ISPP/hotQAthiomersal.shtml.)

786. Only one country has provided information with regard to vaccines containing mercury. In the United States, under the Food and Drug Administration Modernization Act of 1997, FDA is required to assess the risk of all mercury containing food and drugs. Under this provision, FDA asked vaccine manufacturers to provide information about thimerisol content of vaccines. Based on this information, the Public Health Service, the American Academy of Pediatrics, and vaccine manufacturers agreed that thimerisol-containing vaccines should be removed as soon as possible. Manufacturers have been asked for a clear commitment to eliminate mercury from vaccines, and FDA will do expedited reviews of resulting revisions to product license applications.

787. According to the Immunization Safety Office of the WHO, WHO continues to recommend the use of thiomersal-containing vaccines. These vaccines have been used safely throughout the world for decades, helping to save many millions of children's lives. Further, WHO emphasises that the new USA recommendations regarding thiomersal-containing vaccines were based on risk-benefit assessments conducted in the USA and therefore caution should be used in generalising those recommendations to other countries. The potential levels of exposure to thiomersal, and therefore to any health risks, will differ in different countries based on the recommended immunization schedule and the specific vaccines used in each country. (WHO, 2001)

788. **Other products -** A few countries also have regulations that prescribe aspects of user safety for private consumers, for example in toys, textiles, certain chemical preparations, etc. For example, the amount of mercury allowed in a consumer product is under the jurisdiction of Health Canada's *Hazardous Products Act*. Selling, advertising or importing toys, equipment or other products into Canada is prohibited if they may be in contact with children and have a decorative or protective coating containing any compound of mercury.

D. Other standards and programmes

789. **Occupational health and safety -** A number of countries have also implemented measures to ensure occupational safety and health of workers and regulate exposures to mercury in the workplace, often by establishing so-called Permissible Exposure Limits (PELs). Limits vary from country to country, examples can be found in the Appendix mentioned earlier.

790. **Information and reporting requirements –** Several countries have developed systems to collect and disseminate data on environmental releases and transfers of toxic chemicals from industrial facilities, often known as Pollutant Release and Transfer Registers (PRTRs). PRTRs have proven valuable, not only to track the environmental performance of industrial facilities and the effectiveness of government programmes and policies that apply to them, but also to stimulate voluntary initiatives by companies to reduce their releases and transfers of toxic chemicals.

791. An example of such a system is the United State's Toxics Release Inventory (TRI). Starting with the 2000 reporting year, the reporting threshold for mercury and its compounds has been lowered to 5 kilograms per year (the previous threshold was 4500 kilograms). Through this action, the United States will have a much more comprehensive picture of the amounts of mercury and its compounds that are released to the air, water, land, transferred off-site for disposal, transferred off-site for recycling or recycled on-site. Canada also has a PRTR equivalent, the National Pollutant Release Inventory (NPRI).

792. A third example is Australia's National Pollutant Inventory (NPI), which reports information, based on estimation techniques, on the types and amounts of certain chemicals being emitted to the environment. It provides the community, industry and local governments with access to consistent and reliable information about pollutant emissions in Australia. Reporting of emissions is mandatory if an industry surpasses various use thresholds. Reporting for the 1998-1999 and 1999-2000 reporting years

was voluntary, but from 2000-2001 onwards will be compulsory. Enforcement is the responsibility of the relevant Australian State or Territory.

793. **International and regional agreements –** A number of countries also participate in international and regional conventions and agreements, which might set supplementary reduction goals with regard to mercury releases. Such conventions and agreements relevant to mercury are described later in section 9.3.1.

9.2.4 Examples of comprehensive national initiatives to reduce or eliminate uses and releases of mercury

794. The previous section clearly shows that mercury is addressed at national level through a large number of different measures, often aimed at limited specific uses or releases and often involving different ministries and institutions. However, there are some examples of coordinated approaches to obtaining a set goal of reducing or eliminating uses and releases of mercury, involving extensive national regulation of the use and handling of mercury in the society. Descriptions of the national approaches currently being implemented within the European Community and in Sweden and the United States are given below, together with an indication of the reductions in mercury consumption and use that have been obtained through these initiatives. The information in these sections has mainly been extracted from the national submissions (European Community - sub40gov; Sweden – sub28gov, USA – sub23gov). The summary for the USA has been supplemented with information from US EPA - GLNPO (1999).

EUROPEAN COMMUNITY

795. The European Community legislation is of interest in that it must be implemented in all of its15 Member States, representing a significant part of the mercury consumed in Europe.

796. **Water point sources -** Several Community Directives exists, which together limit mercury pollution of inland surface, territorial and internal coastal waters and set Community-wide standards regarding discharges of mercury for a considerable number of industrial sectors. Also, the new Water Framework Directive has been approved, laying down an integrated EU strategy for harmonised water quality standards and controls. Mercury is one of the "priority hazardous substance" covered, and releases in the aquatic environment are to be phased out within 20 years. Necessary measures will be elaborated by the end of 2003.

797. **Waste incineration -** Also, a Community Directive exists on the incineration of waste. The aim of this Directive is to prevent or limit as far as possible the negative effects on the environment, in particular pollution by emissions to air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste. The Directive sets out air emission limit values for waste incineration and co-incineration plants and for discharges of wastewater from the cleaning of exhaust gases. The provisions apply to new installations as from 28 December 2002 and for existing installations as from 28 December 2005.

798. **Integrated pollution prevention and control -** An important Directive of relevance to its efforts to reduce mercury pollution within the Community is EC Council Directive 96/61/EC concerning integrated pollution prevention and control. The aim is to achieve integrated prevention and control of pollution arising from activities such as energy industries, production and processing of metals, mineral industry, chemical industry, waste management and other activities like intense livestock farming, pulp and paper industry and tanneries. The Directive requires such industries to apply best available techniques (BAT) to prevent or, where that is not practicable, to reduce pollution of air, water and land, including measures concerning waste, in order to achieve a high level of protection of the environment as a whole. The Directive includes mercury and its compounds. The requirements apply to new or substantially changed installations by 30 October 1999 and for existing installations after 30 October 2007. As part of implementation of the Directive, reference documents on best available techniques (BREF) are developed for different sectors.

799. **Chlor-alkali production** - There is also a BREF on chlor-alkali production. According to this BREF, best available techniques specific to mercury cell plants include conversion to membrane cell technology - during the remaining life of mercury cell plants, all possible measures should be taken to protect the environment as a whole. The chlor-alkali producers within the EC have expressed their support for the measures set out in this BREF. As a further step they have presented relevant authorities with voluntary commitments[29] made with a view to facilitating the transition away from the mercury-based chlor-alkali process. The producers have renewed their earlier 1995 commitment not to use mercury technology for new plants, not to transfer redundant equipment to third parties for re-use, to further reduce emissions according to a quantified schedule, to ensure transparency in detailed plant-by-plant data reporting, to close or convert the existing plants when they reach the end of their economic life and to ensure the environmentally sound management of metallic mercury from the shutdown cells.

800. **Batteries -** Community-wide directives regulating a number of mercury-containing products exist. The Battery Directive (Directive 91/157/EEC) regulates the permissible amount of mercury in batteries and also mandates separate collection of batteries containing mercury and other heavy metals. The limits on mercury content were tightened further by an amendment to the directive in 1998 (directive 98/101/EC) which requires that member states prohibit, as from 1 January 2000 at the latest, the marketing of batteries and accumulators containing more than 0.0005 percent of mercury by weight, including batteries and accumulators incorporated in appliances. Button cells and batteries composed of button cells with a mercury-content of no more than 2 percent by weight are exempted from this prohibition.

801. **Certain dangerous substances and preparations -** The directive 76/769/EEU on the approximation of the laws, regulations and administrative provisions of the member states relating to restrictions on the marketing and use of certain dangerous substances and preparations prohibits the use of mercury substances in marine anti-fouling paints, wood preservatives, for textile treatment and in industrial water treatment. This “use and marketing” Directive gives a framework and a simplified legislative procedure through which the EU may ban or restrict hazardous chemicals by adding the substances and controls to an annex to the directive. Additions of chemicals and preparations to the legislation have been done in several amendments.

802. **Cosmetics -** According to Directive76/768/EEU (and its amendments 2000/6/EU and 2000/11/EC) on the approximation of the laws of the member states relating to cosmetic products, mercury and its compounds may not be present as ingredients in cosmetics, including soaps, lotions, shampoos, skin bleaching products, etc. (except for phenyl mercuric salts for conservation of eye make-up and products for removal of eye-make-up in concentrations not exceeding 0.007 percent weight to weight) that are marketed within the European Community.

803. **Packaging and packaging waste –** Directive 94/62/EC of 20 December 1994 on packaging and packaging waste aims to harmonize national measures concerning the management of packaging and packaging waste in order to prevent any impact thereof on the environment of all Member States as well as of third countries and also to ensure the functioning of the internal market and to avoid obstacles to trade within the Community. The Directive lays down measures aimed, as a first priority, at preventing the production of packaging waste and, as additional fundamental principles, at reusing packaging, at recycling and other forms of recovering packaging waste and, hence, at reducing the final disposal of such waste. Article 10 of the Directive sets a specific reduction plan for heavy metals present in packaging - the sum of concentration levels of lead, cadmium, mercury and hexavalent chromium present in packaging or packaging components shall not exceed specific, set levels within a time period of 5 years, starting with 600 ppm by weight by 30 June 1998, at the latest, and going down to 100 ppm by weight by 30 June 2001, at the latest.

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[29] “Voluntary Commitments by each Western European Chlor-Alkali Producer (Mercury cells)”, submitted to OSPAR in 1999 and subsequently strengthened. Although submitted in the context of discussions with OSPAR, the commitments are made individually by every producer in Western Europe, including all producers in the EC.

804. **Pesticides -** The sale and use of pesticides for plant protection based on mercury compounds are prohibited by Directive 79/117/EEU and its amendments. This also applies to seed treatment. Export of such preparations to countries outside the European Community is not covered by the Directive.

805. **Vehicles -** European Community Directive 2000/53/EC on end-of life vehicles was adopted 18 September 2000. It lays down measures that aim at prevention of waste from vehicles and promotion of reuse, recycling and other forms of recovery of end-of life vehicles and their components so as to reduce the disposal of waste, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles. According to Article 4 of this Directive mercury, inter alia, is restricted in materials and components of vehicles. Materials and components of vehicles put on the market after 1 July 2003 shall not contain mercury.

Additional measures and initiatives under consideration within the European Community

806. Within the Fourth Framework Programme (1994-1998), the European Commission initiated work to evaluate the appropriateness of EU heavy metals policy to human and environmental risks, especially considering third countries indirectly affected by European Union policy, the so-called EUPHEMET project. The project was also to propose a modified strategy at European Union level, as well as appropriate policies and/or institutions at the international level, with special attention to realising the full potential of existing international institutions. After submission of the report to the European Commission, it has been transformed into a "Handbook for sustainable heavy metals policy and regulation", published in December 2001 by Kluwer Academic Publishers in its book series Environment & Policy. The handbook also contains case studies on mercury, lead and cadmium.

807. Recently, the European Commission released the “Ambient air pollution by mercury (Hg) - Position Paper”. This is a technical report prepared by a number of experts nominated by Member States as part of a working group on mercury. It fulfils the requirement of the Council Directive on Ambient Air Quality Assessment and Management, better known as the Framework Directive (FD) and is aimed to support the preparation of Daughter Directives (DD). The position paper is based on state-of-the-art knowledge of European sources and major processes/ mechanisms that influence the cycle of mercury in Europe and in the global environment, and should be considered as a “snapshot” of current understanding. It recommends that a long-term strategy for the reduction of the methylmercury levels in fish from European waters should be adopted. As a part of this strategy, the working group proposes a specific action plan for reduction of the atmospheric input of mercury to terrestrial and aquatic ecosystems in Europe which includes reductions of mercury emissions from major anthropogenic sources and a complete phase-out of the use of mercury in major goods.

808. **Products -** The European Commission is currently investigating further potential regulatory actions on products containing mercury, in preparation of potential amendments to the marketing and use directive (directive 76/769/EEC). Among others, the following mercury-containing products are reported to be under consideration: Button cell batteries, industrial and control instruments, lighting and thermometers (OSPAR, 2000c). Within these considerations, it is also under discussion whether a full substitution is justified, taking into account the ongoing reduction of mercury use within the European Community versus the substantial mercury emissions from non-product sources like coal combustion (OSPAR, 2001).

809. **Electrical equipment -** A proposal for a new directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment involving mercury is currently under discussion in the European Council and Parliament (RoHS COM, 2000, final). The proposed Directive requires the substitution of mercury in electrical and electronic equipment by 2008. To take into account new scientific evidence, a review of the substitution requirement is envisaged for 2004. The list of exemption could therefore be amended reflecting future technical developments. Switches and other electrical control devices are included, whereas fluorescent lamps up to certain limits (10 mg mercury/lamp) and certain other mercury-containing lamps, are exempted.

SWEDEN

810. Risk reduction of mercury has been an item of high priority in Sweden since the 1960's. In the early 1990's it was concluded that the substantial reduction of mercury releases achieved at point sources would not be sufficient to reduce the environmental load beyond critical levels. It was estimated that mercury content in fish in about 40,000 lakes (i.e. about half of the Swedish lakes) exceeded the limit value of 0.5 mg/kg recommended by the FAO/WHO Codex Alimentarius Commission. In the Government Bill 1990:91/90 "En god livsmiljö" (A living environment), a numerous set of legislative and voluntary actions were proposed, with the ultimate aim of a total phase-out of mercury use. Since then, the set of actions has several times been re-approved and strengthened in various government bills and parliament decisions.

811. Table 9.2 presents some of the major initiatives on mercury use that have been implemented in Sweden as a result of the 1990 overall goal of total phase-out of mercury. It should be noted that Sweden is a Member State of the European Community since 1 January 1995, and is required to implement all Community legislation that applies to mercury, as described in the section on the European Community. However, some of the measures taken in Sweden exceed this legislation.

Table 9.2 Major initiatives on mercury use in Sweden, as reported by Sweden.

Year	Type of release/use	Major initiatives on mercury use in Sweden
1979	Dental releases	There is a voluntary agreement in Sweden since 1979, which requires that all dental clinics are equipped with amalgam separators.
1979	Seed dressings	The use of mercury-containing seed dressings is banned (SFS 1979:349).
1985	Biocides	Import, sale, transfer and use of mercury and mercury compounds as biocides are not approved (SFS 1985:836).
1990	Goal setting - phase-out	Government Bill 1990:91/90 proposed a numerous set of legislative and voluntary actions, with the ultimate aim of a total phase-out of mercury use.
1991	Dental amalgam	The overall goal of a phase-out of mercury also included dental amalgam. This lead to a voluntary reduction of new amalgam fillings in children's teeth from 30 to 1.5 percent between 1991 and 1995. The use in adult's teeth decreased from 32 to 15 %. Since then, total annual sale of mercury in amalgam has levelled off. A further decrease of mercury in fillings for children and teenagers is expected, as a precautionary measure to minimise the exposure of these groups to metal mercury vapour. Dental care compensation ceased to be paid for amalgam fillings in 1999, which has made it more expensive to use amalgam. Although it is still slightly cheaper for most patients to use amalgam than alternative materials, the changed price structure should lead to an additional reduction in use of amalgam.
1992	Clinical thermometers	The import, professional manufacture and sale of clinical mercury thermometers were prohibited from 1 January 1992.
1992	Export of waste	Export of mercury waste and products containing mercury was banned.
1993	Thermometers, measuring instruments and electrical equipment	Professional manufacture, import and sale of thermometers, level switches, pressure switches, thermostats, relays, electrical contacts and other measuring instruments has been banned since 1993. (Ordinance 1991:1290) Some exemptions, mainly for spare parts, still exist. (Ordinance 1998:944). Time-schedule for phase-out is stipulated for each exemption. (Regulation 1998:8)
1993	Goal setting – timing of phase-out	Government Bill 1993/94:163 set a goal of phase-out of mercury and mercury-containing products by the year 2000. When entering the next century, mercury should be offered for sale only in vital products and for uses to which no alternative techniques are known or fully developed.
1998	Batteries	The European Community battery directive that also applies in Sweden was amended in 1998. Batteries with mercury content in excess of 0.0005 % by weight are defined as dangerous for the environment and may not be marketed as such or incorporated into appliances. Button cells with a mercury content of no more than 2 % by weight are exempted. The new rules mean that mercury oxide batteries may no longer be sold – such batteries accounted for 700 of the 800 kg of mercury in batteries in 1997. The new rules have led to a sharp reduction in sold quantities of mercury in batteries - in 1999, the amount of mercury in batteries sold is estimated to approximately 100 kg.

Year	Type of release/use	Major initiatives on mercury use in Sweden
1998	Sewage sludge	In Ordinance 1998:944 the contents of heavy metals in sewage is regulated in cases where sewage sludge is sold or conveyed for agricultural purposes. Regulations for when, where and how much sludge may be used in agriculture are found in SNFS 1994:2 (changed SNFS 1998:4). At present the maximum content of mercury allowed in sludge is 2.5 mg/kg DM (dry matter) and the maximum application is 1.5 g/hectare and year.
1998	Export of mercury	In line with the strict Swedish mercury policy, as of 1 January 1999 metal mercury and chemical compounds and preparations containing mercury may not be exported (Ordinance 1998:944).
2000	New products containing mercury Production processes	Bill 2000/01:65, Chemical Strategy for a Non-Toxic Environment requires that new goods put on the market should be, as far as possible, free from mercury by 2003, at the latest. Also, mercury should not be used in production processes, unless the producer can prove that neither human health nor the environment would be harmed.

Additional measures and initiatives under consideration in Sweden

812. **Chlor-alkali industry -** There are two chlor-alkali plants in Sweden that still use the amalgam process. The more environmentally friendly membrane process is used at one site. In line with OSPAR Decision 90/3, the Swedish government has in several bills stated that the amalgam process should be out of use by 2010. To further assure the realisation of this object on the national level, the Swedish government is considering the inclusion of a ban in Ordinance 1998:944.

813. **Waste products -** As far as waste disposal is concerned, there are separate collection systems and already existing efforts for the collection of batteries, fluorescent lamps, amalgam waste etc. Collected batteries are currently stored awaiting the decision on pre-treatment before it is put in a terminal storage facility for mercury.

814. **Dental amalgam –** The overall goal to a complete phase out of mercury also includes dental amalgam. The consumption of mercury for dental use has decreased significantly after a policy decision by the Parliament in 1994 to phase out the use of dental amalgam. Up to now dental amalgam has been subject primarily to voluntary phasing out measures in Sweden. A voluntary agreement not to use amalgam fillings in the teeth of children and youth up to nineteen has resulted in an almost complete phase out. The Swedish Government is continously investigating further possibilities to reduce the use of dental amalgam.

815. **Laboratory chemicals -** Mercury-containing chemicals for analysis and reagents are mainly used in the environmental control, by its use of mercury sulphate in COD (chemical oxygen consumption) analyses. Information activities have not been effective to phase-out this particular use. The Swedish government is therefore considering an amendment of Ordinance 1998:944, by which the use of mercury in chemicals for analysis and reagents would be banned from 1 January 2004.

816. **Lighting -** There is at present no commercially available, mercury free alternative to linear fluorescent lamps and compacts fluorescent lamps. In order to minimise the environmental impacts from the use of mercury in these products, maximum permitted mercury contents should preferably be established. Such regulations will most likely be introduced in the coming EC Directive on Restrictions of Hazardous Substances in electric and electronic equipment.

817. **Collection of used products and goods -** Recognising that mercury releases from products in use or forgotten "on the user's shelves" would continue for many years, the Government developed an action programme for a more effective and comprehensive collection of used products and goods containing mercury. The action programme included projects dealing with the collection of clinical thermometers, inventories and collection of mercury at different places, clearing out of mercury in schools, universities and colleges and providing information and raising awareness. In projects for the collection of mercury thermometers, economic incentives were used to invite household to turn in their mercury thermometers. Another project consisted of the identification of hidden “technical” mercury in techni-

cal goods and products within about 70 industries. The work involved tracking mercury with the world's first mercury dogs.

818. A total of 10-11 metric tons of mercury have been identified through the action programme, 6-7 of which have been collected and 3.5-4 of which have been labelled for proper disposal once it is not in use anymore. The Government estimates that there are still a number of metric tons of mercury in industry (technical goods, stored metal mercury, etc.), in households (for example in thermometers, antique barometers, doorbells, etc.), in agriculture (old and stored pesticides) and in pipes in the sewage system, especially in pipes from old dental clinics.

819. **Final disposal of mercury -** Mercury is a substance that remains a threat to human health and the environment in perpetuity, and for this reason it should not be recycled. Instead, mercury-containing waste must be dealt with permanently in a safe and environmentally acceptable way. In a report to the Government, the Swedish Environmental Protection Agency in 1997 proposed terminal storage of waste containing mercury in a deep rock facility. A governmental committee has recently submitted its final report on how to dispose waste containing more than 0.1 percent (by weight) of mercury. It is proposed that a mandatory requirement for permanent storage deep down in rock should be in force within five years.

Reductions in mercury consumption and use in Sweden

820. Sweden has conducted evaluations of the efficiency of the legislation and regulation on mercury-containing products. As shown in figure 9.1, the quantified consumption in 1997 of products containing mercury had fallen to approximately one fourth of the consumption in 1991/1992. The reductions in consumption are closely linked to increased use of substitutes to mercury. Possibilities for substitution are described in section 8.2 on substitution. It should be noted that besides legislation, improvements in technological performance have most likely also been an important driving force behind the substitution of mercury in many uses.

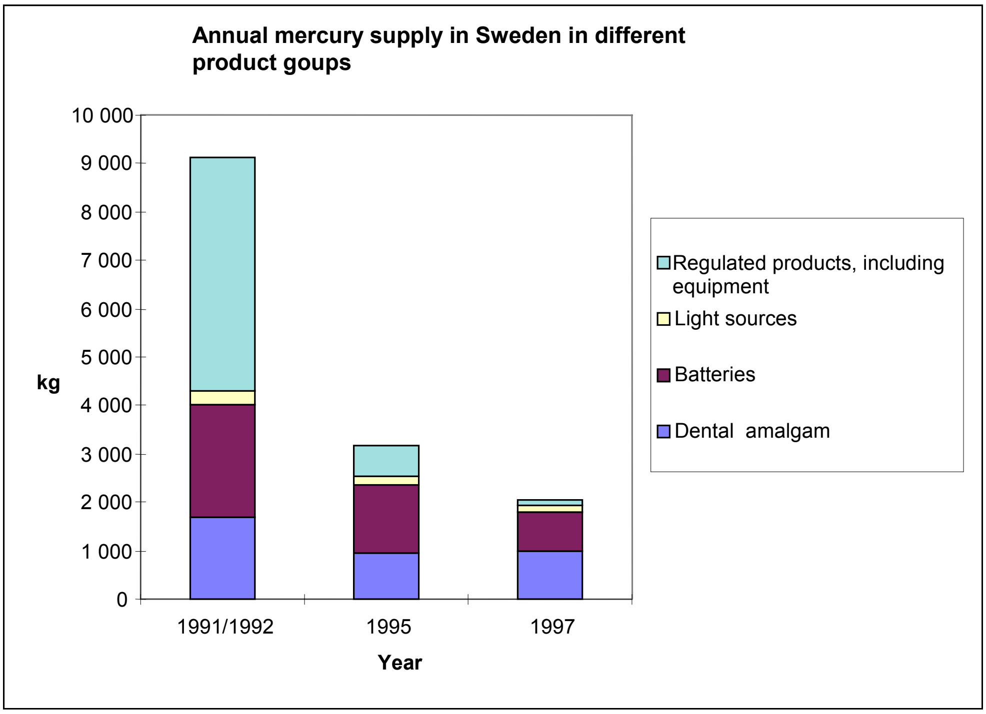

Figure 9.1 Amounts of mercury sold in Sweden in products, including batteries, light sources and dental amalgam, 1991/92, 1995 and 1997, kg/year (KEMI, 1998; original figure presented courtesy of the Swedish Chemicals Inspectorate). Please note that sales of mercury metal (for chlor-alkali production etc) are not included.

UNITED STATES OF AMERICA

821. The United States has been actively addressing the risks posed by exposure to mercury for many years, both through implementation of regulatory activities and voluntary reduction programmes. For example, already in 1991 the US EPA initiated the "33/50 Program", a special programme to help reduce releases of mercury and 16 other toxic substances into the environment. The goal of the programme was to encourage companies to commit to voluntarily reduce their releases of some or all of these toxics by 33 percent by 1992, and 50 percent by 1995. As a result, between 1988 and 1991 environmental releases of mercury were reduced by 38 percent and transfers of mercury for off-site treatment or disposal were reduced by 30 percent (OECD, 1995).

822. Understanding the characteristics and magnitude of mercury releases is critical to the design of effective risk management strategies. The Clean Air Act, as amended in 1990, required US EPA to prepare an assessment of the magnitude of USA mercury emissions by source, the health and environmental effects of the emissions, and the cost and availability of control technologies. The resulting report, *Mercury Study Report to Congress,* was published in December 1997. As the state-of-the-science for mercury is continuously and rapidly evolving, it represents a “snapshot” of current understanding of mercury in the USA. The report is a comprehensive document consisting of eight volumes.

823. The US EPA’s Office of Research and Development (ORD) in September 2000 published its *Mercury Research Strategy*, intended to guide the mercury research programme through 2005. The Strategy identifies the key scientific questions of greatest importance to the Agency, and then describes a research programme to answer those questions. The goal in addressing the questions is to reduce scientific uncertainties limiting US EPA's ability to assess and manage mercury and methylmercury risks. An integral part of the strategy involves study of the atmospheric mercury transport, transformation and fate.

824. To address cross media issues, the US EPA has established a Mercury Task Force to consider strategies for coordinating various programmes for use, management and disposal of mercury. A wide range of options, within a multi-media framework, advocating common-sense pollution prevention programmes are being considered. Some areas which the Task Force will explore include evaluation and information transfer of ongoing prevention and control efforts at local, national and international levels, consideration of pollution prevention ideas including product substitution and innovation, recycling and disposal options and coordination within US EPA for consistent mercury regulatory programmes, as well as coordination with other federal agencies managing mercury.

825. The US EPA is now preparing a National Action Plan for Mercury, based on the findings of the Mercury Study Report to Congress. The Action Plan summarizes major actions to assess and manage mercury problems in the United States, as well as to address the global nature of mercury. It also provides information regarding US EPA’s goals regarding mercury, its positions on numerous mercury issues, its priority actions and brief descriptions of activities it is currently taking and scheduled to take over the next several years. The Plan will likely be available mid-2003.

Ongoing and planned actions to reduce mercury pollution in the United States

826. The United States’ approach to designing effective risk management strategies for mercury comprise both specific regulatory limits on releases and voluntary efforts with industry to reduce mercury use, implemented by a number of agencies at both federal and state levels. The most important are summarized below.

827. **Stockpiles of mercury –** The United States government maintains a supply of mercury as part of the National Defence Stockpile, established at the end of World War I to maintain adequate supplies of materials deemed critical to national defense. The Defense Logistics Agency (DLA), a unit of the Department of Defense, manages the stockpile. The Strategic and Critical Materials Stockpile Act regulates mercury that the DLA sells from the national stockpile. In July 1994, DLA suspended future mercury sales pending analysis of the environmental consequences. An Environmental Impact Statement to determine the disposition of the stockpile is currently being conducted and sales remain sus-

pended pending completion. In the meantime, a complete review of the four facilities across the USA currently storing its mercury and inspection of all the mercury containing flasks to ensure proper and safe storage is being undertaken.

828. **Water point sources -** Mercury is listed as a toxic pollutant under the Clean Water Act. The Clean Water Act regulations specify technology-based effluent limits for mercury discharges from different industries, and describe the circumstances in which states may require effluent limits or monitoring requirements more stringent than technology-based standards. States must set water quality standards for pollutants including mercury. The Clean Water Act relies on a permit system, known as the National Pollutant Discharge Elimination System to regulate direct discharges to surface water bodies. Facilities are assigned a specific mercury discharge limit, and/or are required to monitor their discharge for mercury. Facilities report actual discharge levels in Discharge Monitoring Reports, which serve as the basis for determining compliance. A large number of industry point sources are covered, such as chlor-alkali, steam electric power generation, battery manufacturing etc.

829. **Air point sources** - Mercury and mercury compounds are considered Hazardous Air Pollutants (HAPs) under the Clean Air Act. US EPA established National Emission Standards for Hazardous Air Pollutants (NESHAPs) for mercury emissions based on risk under the pre-1990 version of the Clean Air Act. Under the Clean Air Act Amendments of 1990 US EPA regulates Hazardous Air Pollutant Emissions by source categories using Maximum Achievable Control Technology (MACT) standards for each "major source" in any listed source category. A MACT standard is defined based on an analysis of existing control technology among the best-controlled sources in a given source category.

830. **Chlor-alkali industry -** Emissions from mercury ore processing facilities and mercury cell chlor-alkali plants are limited to a maximum of 2,300 grams/24 hours. US EPA is developing a rule that would further limit mercury emissions from plants that produce chlorine using the mercury cell method. The rule will include emissions limits based on MACT and on management practices, and will shift from the current standard that applies equally to all facilities, regardless of size, to one normalized for production levels.

831. In addition, as a voluntary measure, the Chlorine Institute, on behalf of USA mercury cell chlor-alkali facilities, committed in 1997 to reduce mercury use 50 percent by 2005 and to report annually on progress. In April 2002, the Chlorine Institute provided its fifth annual report, which indicated that mercury consumption by US chlor-alkali factories has declined by 81 percent between 1995 and 2001, or a 75 percent reduction after adjusting for decreases in production capacity. This is a decline from an initial baseline of about 154 metric tons per year to about 28 metric tons during 2001.

832. **Energy production –** The largest anthropogenic source of mercury emissions in the USA is currently coal-fired power plants. On December 14, 2000, the EPA announced the decision that it is appropriate and necessary to regulate hazardous air pollutant emissions (including mercury) from electric utility power plants. A regulation is currently scheduled for proposal by December 15, 2003 and promulgation by December 15, 2004. In order to ensure optimal alternatives are available to reduce mercury emission, the US EPA, the Department of Energy, electric industry groups and some electric companies are working to identify, develop and demonstrate both new and modified technologies for controlling mercury emissions. Working together, these organizations are testing and evaluating the most promising options in the field. Results from this research will be used to support development and implementation of mercury MACT regulation. Moreover, the USA is also considering a proposal from the Bush Administration (called the Clear Skies Initiative) that, if adopted, would achieve significant reductions in mercury emissions from electric power plants as part of a multi-pollutant strategy that would also reduce emissions of sulfur dioxide and nitrogen oxides from these plants through a cap and trade programme.

833. **Waste treatment including incineration -** Prior to 1995, municipal waste combustors and medical waste incinerators were the largest identifiable source of mercury emissions to the atmosphere. Regulations which have been finalized for municipal waste combustors and medical waste incinerators

will, when fully implemented, reduce emissions from these source categories by an additional 90 percent over 1995 levels.

834. As a voluntary measure, US EPA and the American Hospital Association in 1998 signed a memorandum of understanding committing to work together to significantly cut hospital wastes by 2005. The agreement envisions the virtual elimination of mercury-containing hospital wastes and a one-third reduction in total hospital wastes by 2005.

835. In December 1995, the US EPA finalized New Source Performance Standards (NSPSs) and Emission Guidelines (EGs) applicable to **municipal waste combustor (MWC) units** with a capacity greater than 227 metric tons per day (i.e. large MWCs). The mercury air emissions standard for new and existing MWCs is 0.08 milligrams per day standard cubic meter (mg/dscm) at 7 percent oxygen (7 percent O_2). All 167 large MWCs that are subject to the regulations that came into compliance by December 2000 and mercury emissions (based on year 2000 stack test compliance data) from this source category have been reduced by about 95 percent form 1990 levels. The typical performance level was 0.02 mg/dscm. A companion rule (NSPSs and EGs) for a small MWC unit (32 to 227 metric tons per day) was adopted in December 2000 with retrofit required by December 2005. The same mercury emissions limits apply and the same control technology is expected to be used.

836. The USA EP finalized new Source Performance Standards and Emission Guidelines for **Medical Waste Incinerators** (62 FR 48348) in September 1997. The guidelines establish standards that limit emissions from new incinerators. The standards are expected to reduce mercury emissions by 45 to 75 percent. The emission guidelines also require states to develop regulations that limit emissions from existing medical waste incinerators. The emission guidelines are expected to reduce emissions from existing incinerators by 93 to 95 percent. They also require training and qualification of operators, incorporate siting requirements, specify testing and monitoring requirements to demonstrate compliance with the emission limits, and establish reporting and record keeping requirements.

837. Several states, including New York, California and Texas have adopted relatively stringent regulations in the past few years limiting emissions from medical waste incinerators. The implementation of these regulations has brought about very large reductions in emissions of mercury in those states. It has also significantly reshaped how medical waste is managed in those states. Many facilities have responded to state regulations by switching to other medical waste treatment and disposal options to avoid the cost of add-on pollution control equipment. The two most commonly chosen alternatives have been off-site contract disposal in larger commercial incinerators and on-site treatment by other means (e.g., steam autoclaving).

838. **Hazardous waste incinerators –** On February 14, 2002, US EPA promulgated interim emission standards for hazardous waste incinerators, hazardous waste burning cement kilns, and hazardous waste burning lightweight aggregate kilns under joint authority of the Clean Air Act and Resource Conservation and Recovery Act (RCRA). The standards limit emissions of chlorinated dioxins and furans, other toxic organic compounds, toxic metals (including mercury), hydrochloric acid, chlorine gas, and particulate matter. US EPA will issue final standards for these three categories of hazardous waste burning facilities by 2005; in addition, the Agency will develop emission standards for hazardous waste burning industrial boilers and hydrochloric production facilities.

839. **Waste disposal –** The RCRA regulations outline specific classification and disposal requirements for products and wastes that contain mercury. RCRA regulations are waste-specific, not source-specific, and thus may apply to any facility that generates mercury-containing wastes. RCRA regulations describe specific disposal requirements for individual wastes. All mercury-bearing wastes are subject to land disposal restrictions. That is, the mercury concentration in these wastes must be below the regulatory concentration level before the wastes may be land-disposed. For some types of waste, the regulations require a specific treatment, such as recovery of the mercury or incineration. In other cases, only a maximum mercury concentration is required, and any treatment method may be used.

840. RCRA regulations also influence product disposal and recycling options for mercury containing products. Discarded products considered hazardous wastes are subject to storage, transportation, and permitting requirements. Currently, thermostats and fluorescent lamps are included in a "universal waste rule" that eases RCRA restrictions on hazardous waste management and enables states to set up special collection programmes. US EPA issued the universal waste rule (UWR) in 1995. It is designed to reduce the amount of hazardous waste in the municipal solid waste stream, encourage the recycling and proper disposal of some common hazardous wastes, and reduce the regulatory burden on businesses that generate these wastes. Universal wastes are items commonly thrown into the trash by households and small businesses. Although handlers of universal wastes must meet less stringent standards for storing, transporting, and collecting wastes, the waste must comply with full hazardous waste requirements for final recycling, treatment, or disposal. This management structure removes these wastes from municipal landfills and incinerators. In July 1999, US EPA added mercury-containing lamps to the UWR, which already covered batteries, thermostats, and pesticides. In 2002, EPA proposed adding other mercury-containing wastes to the universal waste rule.

841. **Recreational mining** - There is no active mercury mining in the USA. There is also no use of mercury in large-scale gold mining in the USA. There has been minor recovery of mercury by recreational miners in California, but the mercury is recovered as elemental free mercury in stream bottoms as a by-product from historical use. The mercury is incidentally recovered on the sluices of recreational portable dredge operators. The US EPA and California are working on ways to set up collection points for waste mercury to ensure that recreational miners do not dump their waste mercury in streams.

842. **Foodstuffs –** The Food and Drug Administration (FDA) regulates mercury in food, drugs, and cosmetics. FDA sets an action level of 1 ppm methylmercury in fish, shellfish and other aquatic animals, and may remove from commerce foods that violate this action level. FDA has advised women of childbearing age to limit their consumption of shark, swordfish, tilefish and king mackeral based on methylmercury content. States, tribes and territories are responsible for issuing fish consumption advise for locally-caught fish; many state health departments use 0.5 ppm methylmercury as a trigger for such advice. Some States also issue advice on limiting consumption of non-local commercial species (e.g. canned tuna). Comprehensive information about state fish advisories is available at http://www.cfsan.fda.gov/list.html).

843. **Mercury in products -** Mercury-containing products are regulated in several different ways. At a federal level, mercury product regulation has generally centered around health-based reasons to eliminate mercury from products, using the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA) regulations. In recent years, many states have taken a different approach. Restrictions on mercury-containing products, once used sparingly by the federal government, are increasing rapidly at the state level. Certain USA States have initiated a variety of initiatives aimed at reducing mercury releases from the use and disposal of products. These initiatives include notification and labeling requirements to gain information on the mercury content of particular products and inform purchasers that products contain mercury; prohibitions on the sale of a variety of products for which alternatives were deemed readily available such as fever thermometers, dairy manometers, novelty items (toys, shoes), switches in automobiles, and thermostats in residential and commercial applications; concentration limits on other products such as batteries and packaging; restrictions on product disposal so that the products must be segregated from the solid waste stream and ultimately recycled; and state-sponsored collection programmes for items such as fever thermometers, historic dental inventories, and products found in schools.

844. **Batteries –** Between late 1989 and early 1991, all USA manufacturers converted production so that mercury content, except in button and "coin" cells, did not exceed 0.025 percent mercury by weight. A federal law called the Mercury-Containing and Rechargeable Battery Management Act went into effect May 13, 1996. The Act prohibits the sale of:

1) alkaline-manganese batteries containing mercury (alkaline-manganese button cell batteries are limited to 25 mg mercury per button cell),
2) zinc carbon batteries containing mercury,

3) button cell mercuric-oxide batteries for use in the USA, and
4) any mercuric-oxide battery unless the manufacturer identifies a collection site that has all required federal, State, and local government approvals, to which persons may send batteries for recycling and disposal.

The Act contains labelling requirements and encourages voluntary industry programmes by eliminating barriers to funding the collection and recycling or proper disposal of used rechargeable batteries. The Act also grants states the authority to add other batteries to the recycling programme. This federal law followed the lead of several states that passed legislation in the early 1990's limiting the mercury content of batteries.

845. **Cosmetics –** According to the Federal Food, Drug, and Cosmetic Act (FFDCA), mercury use as a preservative or anti-microbial is limited to eye-area cosmetics or ointments in concentrations below 60 ppm. Yellow mercuric oxide is not recognized as a safe and effective ophthalmic anti-infective ingredient.

846. **Dental amalgam –** The Food and Drug Administration (FDA) also regulates dental amalgam under FFDCA. Dental mercury is classified as a Class I medical device, with extensive safety regulations on its use. Dental amalgam alloy is classified as a Class II device, subject to additional special controls.

847. **Electric switches –** Voluntary efforts are underway jointly with appropriate industry and associations to reduce mercury used in electric switches. Several USA States have also enacted or are considering legislation to require end-of-life vehicle handlers and auto manufacturers to establish and maintain a mercury switch removal programme to address the problem of existing switches in vehicles already on the road.

848. **Lighting –** Of the 500-600 million mercury-containing lamps sold in the United States annually, approximately 96 percent are fluorescent lamps. It is estimated that approximately the same number of lamps are disposed of on an annual basis. Mercury releases due to mercury-containing lamps are expected to decrease in the future for a number of reasons. One reason is that states are beginning to view recycling as a viable option to decrease mercury releases. There is presently a bill in Massachusetts that would require every manufacturer of mercury-containing products that may be sold or offered for sale to ensure that proper recycling of these products occurs by funding a collection system. In addition, there have been technological advances in the manufacture of fluorescent lamps. Since the mid-1980's, electrical manufacturers have reduced the average amount of mercury in each fluorescent lamp from an average of 48.2 mg to an average of 11.6 mg/lamp in 1999. A certain amount of mercury is needed, however, in order to maintain desirable properties. A recent survey by the National Electrical Manufacturers Association showed that the average 4-foot (1.22 m) lamp in 2001 contained 8.3 mg of mercury.

849. **Paints -** As of May 1991, all registrations for mercury biocides used in paints were voluntarily canceled by the registrants, thus causing a drastic decrease in the use of mercury in paint. In addition to the paint industry reformulating its paints to eliminate mercury, US EPA banned the use of mercury in interior paint in 1990 and in exterior paint in 1991.

850. **Pesticides -** The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) covers the sale and use of pesticides, including registration of chemicals that meet health and safety tests. Earlier, several mercury compounds were registered as pesticides, bactericides, and fungicides, however, registrations of the last mercury-based pesticides for use to control pink and grey snow mold were voluntarily cancelled by the manufacturer in November 1993.

851. **Thermometers –** Voluntary efforts are underway jointly with appropriate industry and associations to reduce mercury in thermometers through mercury free substitutes. Several USA States have banned the use of mercury fever thermometers, and most major retailers no longer sell them.

852. **Thermostats** - As a voluntary measure, the industry-funded Thermostat Recycling Corporation (TRC) launched a programme in 1997 to recycle mercury-switch thermostats in nine states (see www.nema.org/index_nema.cfm/664/). It has since been expanded to 48 states in the USA, and in 2001 collected 48,215 thermostats and 402 pounds of mercury, for a total of more than 120,000 thermostats and 1,000 pounds of mercury since the programme's inception. Recognizing that the capture rate for the TRC programme is relatively low, two USA States (Maine, Oregon) will prohibit the sale of new mercury thermostats for residential and commercial applications effective January 2006.

853. **Vaccines -** Under the Food and Drug Administration Modernization Act of 1997, FDA is required to assess the risk of all mercury containing food and drugs. Under this provision, FDA asked vaccine manufacturers to provide information about thimerisol content of vaccines. Based on this information, the Public Health Service, the American Academy of Pediatrics, and vaccine manufacturers agreed that thimerisol-containing vaccines should be removed as soon as possible. Manufacturers have been asked for a clear commitment to eliminate mercury from vaccines, and FDA will do expedited reviews of resulting revisions to product license applications.

854. **Vehicles –** The use of mercury-containing switches in vehicles is being gradually phased out through voluntary initiatives. The US EPA’s Environmental Accounting Project is a cooperative effort with business, academia and others to promote sound management accounting and capital budgeting practices that better address environmental costs. The project encourages and motivates business to understand the full spectrum of environmental costs and integrate these costs into decision-making. A car manufacturer in the United States is now removing or replacing all mercury switches that have been traditionally used in its under-hood convenience light applications. By applying the principles of environmental accounting, the company determined that it could cost-effectively replace the mercury switches with a rolling ball switch or remove the switches altogether. For the first group of cars on which the company tested the feasibility of substitution and removal, it determined that it could avoid USA$ 40,000 in costs. Most of those costs were associated with the documentation of the removal of mercury switches from the vehicle before disposal, and with the potential liability for any mercury that enters the environment following vehicle disposal. After conducting their own total cost analyses, other auto manufacturers are now following suit and are actively removing mercury switches from their own automobiles. The auto industry has stated that it will cease production of vehicles with mercury switches in 2002. However, a significant quantity of mercury switches remains in vehicles still in use. Some states have instituted programmes to remove switches, either voluntarily or as a requirement for auto dismantlers.

855. **Occupational safety and health -** The Occupational Safety and Health Administration has responsibility for maintaining safe workplace conditions. OSHA sets permissible exposure levels for elemental mercury in workplace settings. Mercury is listed as a neurotoxin capable of causing behavioral changes, decreased motor function and other effects on the nervous system. OSHA mercury standards also recommend that skin contact should be avoided.

856. Workplace standards may influence the types of processes used at a facility. For example, when OSHA tightens its standards for a particular substance, it may force users of that substance to modify their processes or eliminate use of that substance entirely in order to meet these new standards. Workplace air concentration levels for exposure to elemental mercury: Section 29 CFR 1910.1000 sets the permissible exposure limit (PEL) for an 8-hour time weighted average (TWA) of 0.1 mg/m^3.

857. **Information and reporting requirements –** Under the USA Toxics Release Inventory (TRI), starting with the 2000 reporting year, the reporting threshold for mercury and its compounds has been lowered to 5 kilograms per year (the previous threshold was 4500 kilograms). Through this action, the United States will have a much more comprehensive picture of the amounts of mercury and its compounds that are released to the air, water, land, transferred off-site for disposal, transferred off-site for recycling or recycled on-site within industrial facilities.

858. **Transportation -** The Department of Transportation regulates hazardous materials transport under the Hazardous Materials Transportation Act. Mercury and mercury compounds are hazardous substances subject to packaging, shipping and transportation rules for hazardous materials.

859. **Regional cooperation -** In 1997, the United States and Canada signed the Great Lakes Binational Toxics Strategy. The goal of the strategy is to seek, by 2006, a 50 percent reduction in the deliberate use of mercury and a 50 percent reduction in the release of mercury caused by human activity. The goal applies to all mercury releases nationwide as well as all direct discharges to the Great Lakes Basin. The USA is also co-operating with Mexico and Canada in the North American Regional Action Plan on sound management of chemicals, in which mercury is a priority substance. These regional initiatives are described in more detail later in section 9.5.

Reductions in mercury consumption and use in the United States

860. Figure 9.2 shows the trends in the reported mercury consumption in the USA distributed among industrial sectors as presented by Sznopek and Goonan (2000). The figure shows a decrease in consumption of about 75 percent since the 1970's. The total reported consumption fell by more than 50 percent from a 711 metric tons in 1990 to 372 metric tons just six years later in 1996. According to Sznopek and Goonan (2000), the two major causes of this reduction were the elimination of mercury in batteries by regulation and technological advancements, and elimination of mercury-based fungicides in paints by regulation. Possibilities for substitution of mercury are described in section 8.2 on substitution.

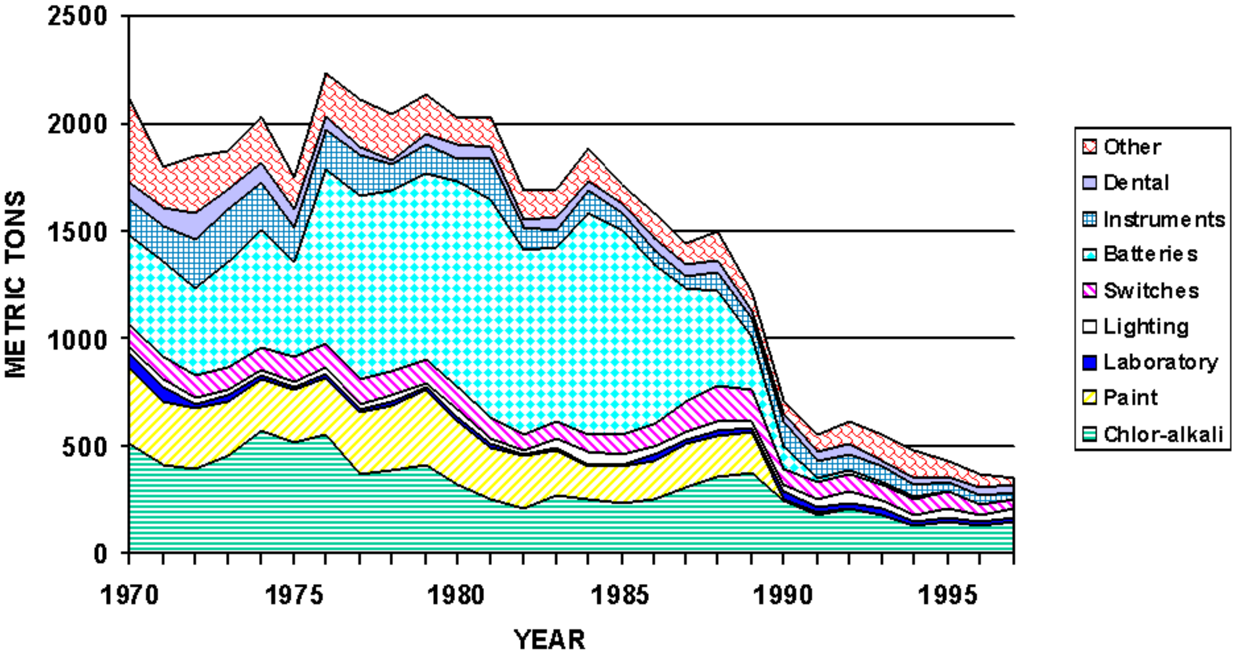

Figure 9.2 US industrial reported consumption of mercury in the period 1970-1997, distributed among industrial sectors (Sznopek and Goonan, 2000; original figure presented courtesy of US Geological Surveys).

9.3 International agreements and instruments

861. There are also a number of international agreements and instruments that contain provisions to manage and control releases and limit use and exposures of mercury. The instruments often define reduction goals or require implementation of specific measures at national level, which supplement national initiatives in the participating countries. An overview of such international initiatives identified in this project and their main characteristics are given in table 9.3. In the following sections are presented summaries of the individual agreements and instruments and their relevance to mercury. The general description of each agreement or instrument has mainly been taken from UNEP (2001). The description of the LRTAP Convention has been supplemented with information from associated websites.

Table 9.3 – Overview of international agreements/instruments containing provisions relating to mercury.

Section	International agreement or instrument	Geographic coverage of agreement or instrument	Agreement or instrument's relevance to mercury	Types of measures addressing mercury set out in the agreement or instrument
9.3.1	LRTAP Convention and its 1998 Aarhus Protocol on Heavy Metals	Central and Eastern Europe, Canada and the United States of America	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions and recommendations, monitoring
9.3.2	OSPAR Convention	North-east Atlantic including the North Sea (including internal waters and territorial sea of Parties)	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions, recommendations, monitoring, information
9.3.3	Helsinki Convention	Baltic Sea (including entrance of the Baltic Sea and drainage areas to these waters)	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions, recommendations, monitoring, information
9.3.4	Basel Convention	Global	Any waste containing or contaminated by mercury or its compounds is considered a hazardous waste and covered by specific provisions	Binding commitments regarding international transport of hazardous waste, procedure for information and approvals on import/export of hazardous waste
9.3.5	Rotterdam Convention	Global	Addresses inorganic mercury compounds, alkyl mercury compounds, alkyl-oxyalkyl compounds and aryl mercury compounds used as pesticides	Binding commitment regarding import/export of those mercury compounds covered, procedures for information exchange and export notification
9.3.6	Stockholm Convention	Global	Mercury compounds are NOT addressed by the Convention	-

9.3.1 The Convention on Long-Range Transboundary Air Pollution and its 1998 Aarhus Protocol on Heavy Metals (LRTAP Convention)

862. The objective of the Convention on Long-Range Transboundary Air Pollution is to protect man and his environment against air pollution and to endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution. The Convention sets up an institutional framework, bringing together policy and research components. It establishes a number of co-operative programmes for assessing and monitoring the effects of air pollution.

863. The Convention requires Parties to develop policies and strategies that will serve as a means of combating the discharge of pollutants, by means of exchanges of information, consultation, research and monitoring. Parties are also required to co-operate in the conduct of research into and/or development of technologies for reducing emissions of major air pollutants, instrumentation and other tech-

niques for monitoring and measuring emission rates and ambient concentrations of air pollutants, improved models for understanding the transmission of long-range transboundary air pollutants, the effects of major air pollutants on human health and the environment and education and training programmes related to the environmental aspects of pollution by major air pollutants. Implementation of the Convention has already contributed successfully in reducing sulphur emissions across Europe, and there has also been progress in reducing emissions of nitrogen oxides and volatile organic compounds.

Geographic coverage and entry into force of the protocol

864. The Convention and its protocols are open to member States of the United Nations Economic Commission for Europe (UNECE), as well as States having consultative status with the UNECE and regional economic integration organizations, constituted by sovereign States Members of the UNECE. The UNECE has 55 member States, mainly from Central and Eastern Europe, but also includes Canada and the United States of America as members. (see http://www.unece.org/oes/eceintro.htm for the list of UNECE member States).

865. The Convention entered into force on 16 March 1983 and had 49 Parties as of 1 October 2002. Since its entry into force, it has been extended by eight protocols, of these the 1998 Aarhus Protocol on Heavy Metals is especially relevant to mercury.

866. The Aarhus Protocol will enter into force on the ninetieth day following the date on which the sixteenth instrument of ratification, acceptance, approval or accession has been deposited with the Depositary. As of 2 October 2002, it had 13 Parties (Canada, Czech Republic, Denmark, Finland, France, Luxembourg, Netherlands, Norway, Republic of Moldova, Sweden, Switzerland, United States of America and the European Community). It has not yet entered into force.

867. The Executive Secretary of the UNECE provides the Secretariat for the Executive Body of the Convention. It does so within the UNECE Environment and Human Settlements Division.

The 1998 Aarhus Protocol on Heavy Metals, and its relevance to mercury

868. The Executive Body of the Convention adopted the Protocol on Heavy Metals on 24 June 1998 in Aarhus, Denmark. It targets three particularly harmful metals: cadmium, lead and mercury, and requires Parties to the Protocol to reduce their releases for these three metals. It aims to cut emissions from industrial sources (iron and steel industry, non-ferrous metal industry), combustion processes (power generation, road transport) and waste incineration. It lays down stringent limit values for emissions from stationary sources and suggests best available techniques for these sources. The Protocol requires Parties to phase out leaded petrol and introduces measures to lower heavy metal releases from other products. Emission levels must be reported using as a minimum methodologies specified by the Steering Body of EMEP, the Cooperative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe.

869. Article 3 describes the basic obligations set out in the Protocol, below is a summary of those especially relevant to mercury.

A) Reduction of total annual emissions of mercury into the atmosphere, compared to the reference year for the Party (1990, or an alternative year between 1985 and 1995 set when becoming a Party), through application of best available techniques, product control measures or other emission reduction strategies.

B) Use of best available techniques for stationary sources - for new plants within 2 years, for existing plants within 8 years. The standards for best available techniques are given as examples in Annex III to the Protocol, and include both cleaning technology and substitution of mercury based technology, for example in chlor/alkali plants.

C) Application of limit values to control emissions from major stationary sources, both new and existing – Limit values for a number of sources are specified in Annex V of the Protocol, for example for particulate emissions from combustion plants, mercury emissions from chlor-alkali plants and mercury emissions from municipal, medical and hazardous waste incineration.

D) Application of product control measures concerning mercury – The Protocol requires Parties to achieve specific mercury levels in alkaline manganese batteries within 5 years, or 10 years for Parties with economies in transition. Alkaline manganese button cells and batteries composed of button cells are exempted from this obligation. In addition, Parties should consider applying additional product control measures as described in Annex VII of the Protocol. Recommendations are given for mercury-containing products such as electric equipment, electrical components (thermostats, switches), measuring devices (thermometers, manometers, barometers), fluorescent lamps, dental amalgam, pesticides including seed dressings, paints and batteries other than alkaline manganese batteries, and include prohibition of specific products, voluntary agreements and recycling programmes.

Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe

870. Associated with the LRTAP-process, the main objective of the EMEP programme (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe) is to regularly provide Governments and subsidiary bodies under the LRTAP Convention with qualified scientific information to support the development and further evaluation of the international protocols on release reductions negotiated within the Convention. Initially, the EMEP programme focused on assessing the transboundary transport of acidification and eutrophication; later, the scope of the programme has widened to address other issues covered by the Convention, such as POPs, heavy metals, including mercury, and particulate matter.

871. The EMEP programme relies on three main elements: (1) collection of emission data, (2) measurements of air and precipitation quality and (3) modelling of atmospheric transport and deposition of air pollution. Through the combination of these three elements, EMEP fulfils its required assessment and regularly reports on emissions, concentrations and/or depositions of air pollutants, the quantity and significance of transboundary fluxes and related exceedances to critical loads and threshold levels. The combination of these components provides also a good basis for the evaluation and qualification of the EMEP estimates.

872. The EMEP programme is carried out in collaboration with a broad network of scientists and national experts that contribute to the systematic collection, analysis and reporting of emission data, measurement data and integrated assessment results. Three different Task Forces - on measurements and modelling, on emission inventories and projections and on integrated assessment modelling - provide for a for discussion and scientific exchange.

873. The coordination and intercalibration of chemical air quality and precipitation measurements are carried out at the Chemical Coordinating Centre (CCC). The storage and distribution of reliable information on emissions and emissions projections is the task of the Meteorological Synthesizing Centre–West in Oslo, Norway. The modelling development for heavy metals and POPs is the responsibility of the Meteorological Synthesizing Centre -East (MSC-E) in Moscow, Russian Federation. In 1999, the Executive Body of the Convention decided to include integrated assessment into the core activities of EMEP and to establish a Center for Integrated Assessment Modelling (CIAM) building on past modelling work, in particular the RAINS (Regional Acidification, Information and Simulation) model.

Application of effects-based approaches when implementing the obligations of the Convention - Critical loads and critical levels

874. The LRTAP Convention also encourages the development and possible application of effects-based approaches to implement the provisions of the Convention in an effective manner, i.e. approaches that take into consideration the exposure man or the environment can be exposed to without experiencing direct adverse effects. One effects-based approach used is based on critical loads[30] and critical

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[30] **Critical load** (deposition) has been defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according

levels[31]. The Coordination Center for Effects (CCE) in the Netherlands, established in 1990, is part of the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends under the LRTAP Working Group on Effects.

875. The CCE scientifically assesses the risks expressed as critical thresholds to forests, lakes and other ecosystems in Europe caused by (long-range) air pollution. This information, which is also summarised in maps of critical thresholds, is useful to understand how national air pollution abatement measures can reduce these risks to ecosystems anywhere in Europe. It also contributes in a novel manner to the scientific support of European air pollution reduction policies. In addition to data on national emissions and costs of emission reductions, now also benefits – in terms of the reduction of risks to ecosystems - can be quantified. The use of this information in integrated assessment models such as RAINS enables the policy analysis of cost-effective emission reductions in Europe. Since the late 80's, methods have been developed to compute and map critical loads of acidity (sulfur and nitrogen based) and of eutrophication (nitrogen based). Attempts at developing critical loads and critical levels for heavy metals, including mercury, are ongoing.

9.3.2 The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)

876. The objectives of the 1992 OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic are to take all possible steps to prevent and eliminate pollution and take the necessary measures to protect the sea area against the adverse effects of human activities and to safeguard human health and to conserve marine ecosystems and, where practicable, to restore marine areas which have been adversely affected. The Convention contains annexes addressing different sources of pollution, such as prevention and elimination of pollution from land-based sources; prevention and elimination of pollution by dumping or incineration (which prohibits incineration); prevention and elimination of pollution from offshore sources; assessment of the quality of the marine environment and protection and conservation of the ecosystems and biological diversity of the maritime area.

Geographic coverage and entry into force

877. The OSPAR Convention is open to Parties to the "Oslo" and "Paris" Conventions (i.e., the Convention for the Prevention of Marine Pollution from Land-Based Sources and the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft), any other coastal state bordering the maritime area, any state located upstream on watercourses reaching the maritime area or any regional economic integration organisation having a member state that qualifies. The maritime area covers the north-east Atlantic including the North Sea and comprises the internal waters and the territorial sea of Parties, the sea beyond and adjacent to the territorial sea under the jurisdiction of the coastal state, and the high seas. Other States or regional economic organisations that do not satisfy the criteria may be invited unanimously by the Parties to accede to the Convention.

878. The OSPAR Convention came into force on 25 March 1998. It replaced the Paris and Oslo Conventions. However, Decisions, Recommendations, and other agreements adopted under the two previous Conventions continue to be applicable, unaltered in their legal nature, unless they are terminated by measures adopted under the OSPAR Convention. The OSPAR Convention currently has 16

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to present knowledge". Thus, a critical load is an indicator for sustainability of an ecosystem in that it provides a value for the maximum allowable deposition of a pollutant below which the risk of damage is reduced. Establishing a relationship between the biology and the physico-chemical properties of an ecosystem, its sensitivity to a pollutant's deposition, i.e. the critical load, can be calculated from its physical and chemical properties. This information on ecosystem sensitivity can be compared with deposition data to determine which areas receive deposition levels exceeding the critical loads in that area.

[31] Parallel to the development of critical loads, **critical levels** (concentrations) have been developed, which are defined as "concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur according to present knowledge". In contrast to critical loads, a single critical value is derived for every type of ecosystem (crops, forests, semi-natural vegetation), independent of site characteristics.

Parties (Belgium, Denmark, European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland).

879. The OSPAR Commission, with representatives of each of the Parties, is the governing body of the Convention. The Commission meets annually, sometimes at ministerial level.

The OSPAR Strategy with regard to Hazardous Substances, and its relevance to mercury

880. In 1998 at Sintra, Portugal, the first ministerial meeting of the OSPAR Commission adopted, among others, a Strategy with regard to Hazardous Substances, with a view to the further implementation of the OSPAR Convention, which had just came into force. The objective of the Strategy is to prevent pollution of the maritime area by continuing to reduce discharges, emissions and losses of hazardous substances, with the ultimate aim of achieving concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances.

881. The Strategy also includes a timeframe, setting out the basis for OSPAR's work for achieving the objective - every endeavour will be made to move towards the target of cessation of discharges, emissions and losses of hazardous substances by the year 2020.

882. To this end, a process has been established to identify the OSPAR list of chemicals for priority action. This list was revised in 2001, and currently contains 42 substances or groups of substances, including mercury and organic mercury compounds. These chemicals are being addressed by preparing (for those in use in the OSPAR area) background documents for each substance or group specifying the sources of inputs of them to the marine environment, the threat posed and possible measures. Such measures are then considered. An OSPAR Background Document on Mercury and Organic Mercury Compounds (OSPAR Commission, 2000) was endorsed by OSPAR in 2000 and the actions recommended there are taken into account, as appropriate, in the work of OSPAR.

883. There are several measures applicable under OSPAR to control mercury emissions, discharges and losses from specific sectors, e.g. the measures related to the chlor-alkali industry and *PARCOM Decision 85/1 on Limit Values and Quality Objectives for Mercury Discharges by Sectors other than the Chlor-alkali Industry*. Furthermore, OSPAR measures on Best Available Techniques (BATs) for various industrial installations and the offshore gas and oil installations will also help to limit discharges, emissions and losses of mercury.

884. With regards to the **chlor-alkali sector**, there are a number of measures applicable as regards the control of mercury in discharges to water and emissions to air. In *PARCOM Decision on New Chlor-Alkali Plants Using Mercury Cells, 1982* the Commission decided that authorisations for new chlor-alkali plants might be granted by Parties only if such authorisations were based on application of best technical means available for preventing discharges of mercury. Best technical means available at that time made it possible to limit discharges of mercury using the recycled-brine process to less than 0.5 g/metric ton of installed chlorine production capacity. Furthermore, the Commission agreed that when the construction of new plants was being considered, the use of mercury-free technology, in particular membrane cells should be encouraged whenever circumstances permitted.

885. In *PARCOM Decision 90/3 on Reducing Atmospheric Emissions from Existing Chlor-Alkali Plants,* adopted on 14 June 1990, the Parties agreed that existing mercury based chlor-alkali plants would be required to meet by 31 December 1996 a standard of 2g Hg/t Cl_2 capacity for emissions to the atmosphere, unless there was a firm commitment that the plant would be converted to mercury-free technology by the year 2000. It also agreed that mercury in hydrogen released to the atmosphere, or burnt, would be included in this standard. They also recommended that existing mercury cell chlor-alkali plants be phased out as soon as practicable and set the objective of complete phase-out by 2010. The chlor-alkali producers within the OSPAR area have met the emissions reduction requirements of PARCOM 90/3. In order to make progress towards the other recommendations within this decision they have presented six voluntary commitments with OSPAR. The details are provided in section 3.2.4 EUROPEAN COMMMUNITY in the description on chlor-alkali production.

886. The main tools for controlling releases of **mercury from products** are the placing of restrictions on the marketing and use of the products, or the development of products containing non-hazardous substitutes for mercury.

887. **Mercury discharges from the dental sector** - Several PARCOM Recommendations relating to the reduction of mercury discharges from dental sources are applicable under OSPAR. In 1981, the Paris Commission recommended the installation of special filters in dental surgeries and clinics to collect the residues of mercury amalgams. *PARCOM Recommendation 89/3 on Programmes and Measures for Reducing Mercury Discharges from Various Sources* urges that alternative materials to dental amalgams should be used where appropriate and where excessive cost can be avoided. Surplus or old amalgam should be trapped and separated efficiently, then sent for recovery of the mercury content. *PARCOM Recommendation 93/2 on Further Restrictions on the Discharge of Mercury from Dentistry* states that equipment should be installed to separate water and amalgam to enable collection of the amalgam as from 1 January 1997.

888. **Mercury in batteries** - *PARCOM Decision 90/2 on Programmes and Measures for Mercury and Cadmium-Containing Batteries* lays down various measures dealing with the recovery, disposal and marketing and use of certain mercury and cadmium batteries.

889. **Pesticides containing mercury** - PARCOM Recommendation 89/3 also proposed measures on restricting the use of biocides and pesticides containing mercury.

890. **Industrial, laboratory and medical control instruments and electrical equipment** - PARCOM Recommendation 89/3 also proposes measures on recycling mercury used in such equipment and encouraged the use of equipment not containing mercury, whenever replacements become available at comparable costs. Some Parties have initiated actions for example to limit the use of mercury thermometers, to encourage the development of low-mercury lighting and to establish recycling and special collection schemes.

9.3.3 The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention)

891. The objectives of the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area, adopted on 9 April 1992, are to take all appropriate measures, individually or by means of regional co-operation, to prevent and eliminate pollution in order to promote the ecological restoration of the Baltic Sea Area and the preservation of its ecological balance.

892. The Convention establishes fundamental principles and obligations, as set out in Article 3, whereby Parties are obliged to:

- Take all appropriate legislative, administrative and other measure to prevent and eliminate pollution in order to promote the ecological restoration of the Baltic Sea Area and the preservation of its ecological balance;
- Apply the precautionary principles;
- Promote the use of Best Environmental Practice and Best Available Technology;
- Apply the polluter-pays principle;
- Ensure that measurements and calculations of emissions from point sources and of inputs from diffuse sources are carried out in a scientifically appropriate manner in order to assess the state of the marine environment and ascertain the implementation of the Convention; and
- Use their best endeavours to ensure the implementation of the Convention does not cause transboundary pollution in areas outside the Baltic Sea Area, nor lead to unacceptable strains on the environment or increased risk to human health.

Geographic coverage and entry into force

893. The Helsinki Convention is restricted to the States and the European Community that participated in the 1992 Helsinki Conference and have ratified the Convention. Others can become a party

upon invitation by all the Parties. The Convention covers the Baltic Sea and the entrance of the Baltic Sea and the drainage areas to these waters. Internal waters are included.

894. The 1992 Helsinki Convention replaces the 1974 Convention on the Protection of the Marine Environment of the Baltic Sea Area. It entered into force on 17 January 2000. As of October 2002, the Helsinki Convention had 10 Parties (Denmark, Estonia, European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden).

895. The governing body of the Convention is the Helsinki Commission - Baltic Marine Environment Protection Commission (HELCOM). HELCOM meets annually and, from time to time, meetings are held at ministerial level.

The HELCOM Strategy to Implement its Objective with regard to Hazardous Substances, and its relevance to mercury

896. In 1998 HELCOM established an objective with regard to hazardous substances and a strategy to implement the objective, through the adoption of HELCOM Recommendation 19/5. The objective is to prevent pollution of the Convention Area by continuously reducing discharges, emissions and losses of hazardous substances towards the target of their cessation by the year 2020, with the ultimate aim of achieving concentrations in the environment near background values for naturally occurring substances and close to zero for man-made synthetic substances. A total of 42 chemicals have so far been selected by HELCOM for immediate priority action, including mercury and its compounds.

897. HELCOM has adopted a number of recommendations specifically relating to mercury:

- HELCOM Recommendation 6/4 (adopted 13 March 1985): Recommendation concerning measures aimed at the reduction of mercury resulting from dentistry.
- HELCOM Recommendation 13/4 (adopted 5 February 1992, under revision): Atmospheric pollution related to the use of scrap material in the iron and steel industry.
- HELCOM Recommendation 14/5 (adopted 3 February 1993, under revision): Reduction of diffuse emissions from used batteries containing heavy metals (mercury, cadmium, lead).
- HELCOM Recommendation 16/8 (adopted 15 March 1995): Limitation of emissions into atmosphere and discharges into water from incineration of household waste
- HELCOM Recommendation 17/6 (adopted 12 March 1996): Reduction of pollution from discharges into water, emissions into the atmosphere and phosphogypsum out of the production of fertilizers
- HELCOM Recommendation 18/2 (adopted 12 March 1997): Offshore activities.
- HELCOM Recommendation 19/5 (adopted 26 March 1998): HELCOM objective with regard to hazardous substances.
- HELCOM Recommendation 23/4 (adopted 6 March 2002, superseding 18/5): Measures aimed at the reduction of mercury pollution resulting from light sources and electrical equipment
- HELCOM Recommendation 23/6 (adopted 6 March 2002, superseding 6/3): Reduction of emissions and discharges of mercury from chlor-alkali industry.
- HELCOM Recommendation 23/7 (adopted 6 March 2002, superseding 16/6): Reduction of discharges and emissions from the metal surface treatment.
- HELCOM Recommendation 23/11 (adopted 6 March 2002, superseding 20E/6): Requirements for discharging of waste water from the chemical industry.
- HELCOM Recommendation 23/12 (adopted 6 March 2002, superseding 16/10): Reduction of discharges and emissions from production of textiles.

898. The HELCOM strategy on hazardous substances, including mercury, in many areas parallels the work implemented within the context of the OSPAR Convention.

9.3.4 The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention)

899. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, adopted on 22 March 1989, strictly regulates the transboundary movements of hazardous wastes and establishes obligations for its Parties to ensure that such wastes are managed and disposed of in an environmentally sound manner. The main principles of the Basel Convention are:

- transboundary movements of hazardous wastes should be reduced to a minimum consistent with their environmentally sound management;
- hazardous waste generation should be reduced and minimised;
- hazardous wastes should be treated and disposed of as close as possible to their source of generation; and
- efforts should be made to assist developing countries and countries with economies in transition with the environmentally sound management of hazardous and other wastes they generate.

900. The Basel Convention provides a comprehensive framework to assure the environmentally sound management of hazardous wastes, which includes a control regime for the monitoring and control of transboundary movements of such wastes. Imposed restrictions on transboundary movements include the prohibition of shipment with non-Parties, and the need to receive a written confirmation from the relevant authorities in the country of import accepting the import.

901. A decision to amend the Convention was adopted in September 1995 in order to ban exports of hazardous wastes for final disposal, recovery or recycling from countries listed in a new Annex VII (Parties and other States which are members of OECD, EC, Liechtenstein) to non-Annex VII countries.

Geographic coverage and entry into force

902. The Basel Convention is open to all States and political and/or regional economic integration organisations.

903. The Convention entered into force on 5 May 1992. As of 25 September 2002, there are 152 Parties to the Convention (see http://www.basel.int for individual Parties) and 32 Parties had ratified the amendment, which requires 62 ratifications to enter into force.

904. The Conference of the Parties (COP) is the governing body of the Basel Convention. Subsidiary bodies have been established, such as the Technical Working Group responsible for the preparation of technical guidelines for the environmentally sound management of hazardous wastes, the classification and hazard characterisation of wastes and other tasks. Another subsidiary body is the Legal Working Group which addresses legal matters such as those related to illegal traffic, bilateral and multilateral agreements, settlement of disputes, monitoring of compliance and liability and compensation for damage resulting from transboundary movements of hazardous wastes and their disposal. The fifth meeting of the Conference of the Parties also established a Working Group for Implementation to monitor implementation of the Convention.

The Basel Convention's relevance to mercury

905. According to Article 1, paragraph 1 (a) of the Convention, any waste containing or contaminated by mercury or its compounds is considered a hazardous waste and is covered by the provisions of the Convention.

906. More precisely, Annex VIII provides a list of wastes characterized as hazardous wastes under the Basel Convention Article 1.1(a), not precluding the use of Annex III (list of hazardous characteristics) to demonstrate that a waste is not hazardous. Hazardous wastes containing mercury may be found under the following Annex VIII categories (the list below is not meant to be considered exhaustive):

- A1010 - Metal wastes and waste consisting of alloys of any of the following: (…), Mercury, (…);

- A1030 - Wastes having as constituents or contaminants any of the following: (…), Mercury; mercury compounds, (…);
- A1150 - Precious metal ash from incineration of printed circuit boards not included on list B;
- A1180 - Waste electrical and electronic assemblies or scrap containing components such as accumulators and other batteries included on list A, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or contaminated with Annex I constituents (e.g., cadmium, mercury, lead, polychlorinated biphenyl) to an extent that they possess any of the characteristics contained in Annex III (note the related entry on list B B1110;
- A4020 - Clinical and related wastes; that is wastes arising from medical, nursing, dental, veterinary, or similar practices, and wastes generated in hospitals or other facilities during the investigation or treatment of patients, or research projects

Obligations of the Basel Convention applicable to mercury containing wastes

907. The transboundary movements of mercury containing wastes that can be considered falling within the scope of the Basel Convention would need to be controlled according to the obligations of the Convention. This applies to hazardous wastes containing mercury that are exported for reuse, recovery, recycling and/or for final disposal.

908. In addition, the general obligations of the Basel Convention concerning the need to manage in an environmentally sound manner hazardous wastes would apply to such wastes, including those not being shipped abroad for recovery or disposal operations, but requiring to be managed locally (examples include hazardous wastes from the chlor/alkali process, gold mining, discarding of end-of-life equipments, etc).

9.3.5 The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (Rotterdam Convention)

909. The objectives of the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, adopted on 10 September 1998, are:

- To promote shared responsibility and co-operative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm; and
- To contribute to the environmentally sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export, and by disseminating these decisions to Parties.

910. The Convention establishes the principle that export of a chemical subject to the Convention can only take place with the prior informed consent of the importing party. It establishes procedures for formally obtaining and disseminating the decisions of importing countries as to whether they wish to receive future shipments of specified chemicals and for ensuring compliance to these decisions by exporting countries. It also contains provisions for the exchange of information among Parties about potentially hazardous chemicals that may be exported and imported.

911. The Convention establishes a specific procedure to identify and include chemicals in the Convention, based on actions taken by Parties to ban or severely restrict the use of a pesticide or industrial chemical or a Party is experiencing problems with a severely hazardous pesticide formulation under conditions of use. The Convention initially covers 22 pesticides (including five severely hazardous pesticide formulations) and five industrial chemicals, but many more are expected to be added in the future.

912. For each chemical subject to the Convention, a "decision guidance document" (DGD) containing information concerning the chemical and the regulatory decisions to ban or severely restrict the chemical for health or environmental reasons and information on alternatives, is circulated to importing

countries. These countries are given nine months to respond concerning the future import of the chemical. The response can consist of either a final decision (to allow import of the chemical, not to allow import, or to allow import subject to specified conditions) or an interim response. Decisions by an importing country must be trade neutral (i.e., apply equally to domestic production as well as to imports).

913. The decisions of the importing country Parties are circulated semi-annually via a PIC Circular, and exporting country Parties are obligated under the Convention to take appropriate measure to ensure that exporters within its jurisdiction comply with the decisions.

Geographic coverage and entry into force

914. The Rotterdam Convention is open to all States and regional economic integration organisations. It builds on the existing voluntary PIC procedure, operated by UNEP and FAO since 1989, and takes into account experience gained during the implementation of the voluntary procedure (as set out in the London Guidelines for the Exchange of Information on Chemicals in International Trade and the FAO International Code of Conduct on the Distribution and Use of Pesticides).

915. The Convention will enter into force 90 days after the 50th instrument of ratification, acceptance, approval or accession has been deposited with the Depositary. As of 23 October 2002, the Convention had 34 Parties (Austria, Belgium, Bulgaria, Cameroon, Canada, Czech Republic, El Salvador, Gambia, Germany, Guinea, Hungary, Italy, Jamaica, Jordan, Kyrgyzstan, Libyan Arab Jamahiriya, Luxembourg, Malaysia, Mongolia, Netherlands, Nigeria, Norway, Oman, Panama, Samoa, Saudi Arabia, Senegal, Slovenia, South Africa, Suriname, Switzerland, Thailand, United Arab Emirates, United Republic of Tanzania). It has not yet entered into force.

916. The Convention establishes a Conference of the Parties (COP) to oversee implementation and a Chemicals Review Committee to review notifications and proposals from Parties and make recommendations on which chemicals should be subject to the Convention. It also establishes a Secretariat, whose functions are to be performed jointly by UNEP and FAO.

917. During the interim period before the Convention enters into force, the provisions of the Convention will be implemented on a voluntary basis by participating governments. The Intergovernmental Negotiating Committee that negotiated the Convention will oversee the implementation of the interim PIC procedure, including the addition of new chemicals on an interim basis. The COP will, at its first meeting, decide on the inclusion in the Convention of chemicals that have been added to the PIC procedure during the interim period.

The Rotterdam Convention’s relevance to mercury

918. The Rotterdam Convention’s provisions apply to two categories of chemicals: pesticide and/or industrial chemical. At present, inorganic mercury compounds, alkyl mercury compounds, alkyloxyalkyl compounds and aryl mercury compounds used as pesticides are covered by the Convention. It does not apply to these mercury compounds if they are intended for industrial use. The Convention does not make any specific recommendations with regards to reducing or eliminating use of these mercury compounds as pesticides, however, it ensures that international trade does not take place if an importing Party decides to prohibit use of these compounds as pesticides in the country.

9.3.6 The Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention)

919. The objective of the Stockholm Convention, adopted on 22 May 2001, is to protect human health and the environment from persistent organic pollutants, mindful of the precautionary approach as set forth in Principle 15 of the Rio Declaration on Environment and Development.

920. The Convention creates legally binding obligations for Parties to prohibit and/or take the legal and administrative measures necessary to eliminate the production and use of nine POPs (aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, PCBs and toxaphene) and to restrict the

production and use of DDT. In addition, Parties are obliged to take measures to reduce releases from anthropogenic sources of dioxins, furans, PCB and HCB, with the goal of minimisation and, where feasible, ultimate elimination of these POPs. Parties should also take measures to reduce or eliminate releases from stockpiles and wastes. Furthermore, the Convention establishes a register for country-specific exemptions.

921. The Convention covers pesticides, industrial chemicals and by-products that share the characteristics of POPs, i.e., persistence, bioaccumulation, potential for long-range transport, and toxicity. Initially, 12 chemicals are covered. The Convention contains provisions for adding substances to the Convention through a stepwise procedure initiated by a Party submitting a proposal for adding a substance. The candidate substance is first screened against agreed criteria and then further evaluated in depth by a subsidiary body, the POPs Review Committee. The Review Committee makes a recommendation to the Conference of Parties, who decides on whether to include the substance or not.

922. Annex D of the Convention sets out the screening criteria upon which a decision to include a chemical in the Convention must be based. The criteria include persistence, bio-accumulation, potential for long-range environmental transport, evidence of adverse effects to human health or to the environment, toxicity or ecotoxicity data that indicate the potential for damage to human health or to the environment and the need for global control.

Geographic coverage and entry into force

923. The Stockholm Convention is open to all States and regional economic integration organisations.

924. The Convention will enter into force 90 days after the 50th instrument of ratification, acceptance, approval or accession has been deposited with the Depositary. As of 4 October 2002, the Convention had 23 Parties (Austria, Botswana, Canada, Czech Republic, Democratic People's Republic of Korea, Fiji, Finland, Germany, Iceland, Japan, Lesotho, Liberia, Nauru, Netherlands, Norway, Rwanda, Saint Lucia, Samoa, Slovakia, South Africa, Sweden, United Arab Emirates, Viet Nam). It has not yet entered into force.

925. The Convention establishes a Conference of the Parties (COP) to oversee implementation and a Persistent Organic Pollutants Review Committee to review proposals from Parties for adding substances to the Convention. The Convention also establishes a Secretariat, whose functions are to be performed by UNEP.

926. During the interim period before the Convention enters into force, the Intergovernmental Negotiating Committee (INC) that adopted the Convention will continue to meet to oversee implementation during the interim period and to prepare for the first COP. The focus during the interim period will be on activities that facilitate a rapid entry into force and effective implementation of the Convention.

The Stockholm Convention's relevance to mercury

927. Mercury is not among the chemicals covered by the Stockholm Convention as adopted. During the interim period before the Convention enters into force, States have been encouraged to do preparatory work for listing of additional substances in the Convention. However, the subsidiary body that will make recommendations to the COP on whether to include a substance or not, will not be established until the Convention enters into force. New chemicals will thus only be added once the Convention enters into force.

9.3.7 Main references for this section

928. The main references used in this section are, in addition to those submitted by the organizations:

- UNECE website - http://www.unece.org/env/lrtap/hm_h1.htm;
- EMEP website - http://www.emep.int/index.html;

- Coordination Center for Effects (CCE) website - http://www.rivm.nl/cce/;
- OSPAR Commission website at http://www.ospar.org, OSPAR Commission (2000): OSPAR Background Document on Mercury and Organic Mercury Compounds;
- PARCOM Decisions at http://www.ospar.org/eng/html/welcome.html;
- HELCOM website – http://www.helcom.fi,
  Recommendations - http://www.helcom.fi/helcom/recommendations.html;
- Basel Convention website – http://www.basel.int;
- Rotterdam Convention website – http://www.pic.int;
- Stockholm Convention website –.http://www.pops.int.

9.4 International organizations and programmes

929. A number of international organizations and programmes also have activities aimed at addressing the adverse impacts of mercury on health and the environment. An overview of such international organizations and programmes are given in table 9.4. In the following sections are presented summaries of the organizations and programmes and their relevance to mercury. The general description of each organization or programme has mainly been taken from UNEP (2001).

Table 9.4 - Overview of international organizations and programmes with activities addressing the adverse impacts of mercury on health and the environment.

Section	International organization or programme	Geographic coverage	Organization or programme's relevance to mercury	Types of activities addressing mercury
9.4.1	IARC	Global	Addresses the evaluation of carcinogenic risk of chemicals, including mercury, to humans	Evaluations on individual chemicals, information, guidelines
9.4.2	ILO	Global	Addresses occupational health and safety issues linked with use of chemicals, including small-scale mining activities and mercury	Information, guidelines, capacity building
9.4.3	IPCS	Global	Addresses health and environmental aspects of mercury (including inorganic mercury and methylmercury)	Information (risk evaluations, scientific data and precautionary information)
9.4.4	OECD	OECD member States	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Information, recommendations
9.4.5	UNEP GPA	Global	Addresses heavy metals, including mercury	Goal definition, guidelines
9.4.6	UNIDO	Global	Addresses environmentally sustainable industrial activities, including artisanal mining	Information, guidelines, capacity building
9.4.7	World Bank	Global	Addresses environmentally sustainable industrial activities, including artisanal mining	Information, guidelines, capacity building

9.4.1 The International Agency for Research on Cancer (IARC)

930. The International Agency for Research on Cancer (IARC) is part of the World Health Organization. IARC's mission is to coordinate and conduct research on the causes of human cancer, the mechanisms of carcinogenesis, and to develop scientific strategies for cancer control. The Agency is involved in both epidemiological and laboratory research and disseminates scientific information through publications, meetings, courses, and fellowships. The Agency's work has four main objectives - monitoring global cancer occurrence, identifying the causes of cancer, elucidation of mechanisms of carcinogenesis and developing scientific strategies for cancer control. An important aspect of IARC's work is the publication of the IARC Monographs series. The Monographs are authoritative independent assessments by international experts of the carcinogenic risks posed to humans by a variety of agents, mixtures and exposures. Since its inception in 1972, the series has reviewed more than 860 agents, and

the Monographs have become well-known for their thoroughness, accuracy and integrity. They are invaluable sources of information both for researchers and for national and international authorities.

931. The Monographs represent the first step in carcinogenic risk assessment, which involves examination of all relevant information in order to assess the strength of the available evidence that certain exposures could alter the incidence of cancer in humans. The second step is quantitative risk estimation. Detailed, quantitative evaluations of epidemiological data may be made in the Monographs, but without extrapolation beyond the range of the data available. The Monographs may assist national and international authorities in making risk assessments and in formulating decisions concerning any necessary preventive measures. The evaluations of IARC working groups are scientific, qualitative judgements about the evidence for or against carcinogenicity provided by the available data. These evaluations represent only one part of the body of information on which regulatory measures may be based. Other components of regulatory decisions may vary from one situation to another and from country to country, responding to different socioeconomic and national priorities. Therefore, no recommendation is given with regard to regulation or legislation, which are the responsibility of individual governments and/or other international organizations.

932. In 1993, IARC published Volume 53 of the IARC Monographs, which also covered mercury and mercury compounds. In its overall evaluation of carcinogenicity to humans, methylmercury compounds were classified in Group 2B (possibly carcinogenic to humans) and metallic mercury and inorganic mercury compounds in Group 3 (not classifiable as to their carcinogenicity to humans). (IARC, 1993)

9.4.2 International Labour Organization (ILO)

933. The International Labour Organization, ILO, was founded in 1919 and is the UN specialised agency that seeks the promotion of social justice and internationally recognised human and labour rights. Within the UN system, the ILO has a unique tripartite structure in which workers and employers participate as equal partners with governments in the work of its governing organs. The ILO formulates international labour standards in the form of conventions and recommendations, setting minimum standards of basic labour rights. It provides technical assistance in a range of areas, including occupational safety and health. It promotes the development of independent employers' and workers' organisations and provides training and advisory services to those organisations.

934. With respect to chemical safety, the long-term objective of ILO is to enhance the capacity of government institutions, employers, workers and their representative organisations, as well as non-governmental organisations, to enable them to participate in the design, implementation and evaluation of policies and programmes to improve working conditions and the working environment and to reduce the number of occupational accidents and work-related diseases. In the field of chemicals control, there have been a number of conventions, recommendations and guidance materials issued, including the Convention concerning the Prevention of Major Industrial Accidents (No. 174) and accompanying Recommendation (No. 181), adopted in 1993 and the Convention concerning Safety in the Use of Chemicals at Work (No.170) and its accompanying Recommendation (No. 177), adopted in 1990. The purpose of the last Convention is to protect workers from risks associated with the use of chemicals at their workplace. It sets out responsibilities of employers, suppliers, and workers. States ratifying the Convention are required to work out a national policy for safety in the use of chemicals at work in accordance with specified principles, adopt classification and labelling systems for all such substances, and introduce chemical safety data sheets.

935. Other standards and guidance documents concerned with chemical safety include a number of other conventions and recommendations addressing the risks of specific toxic substances including asbestos, white lead, and benzene. In addition, ILO has published Occupational Exposure Limits For Airborne Substances Harmful to Health: A Code of Practice (1991) and Guidelines on Occupational Safety and Health Management Systems (2001).

936. ILO is also active in the field of small-scale mining and how best to support it as a safe, healthy, productive and sustainable activity. In 1999 it published a report – *Social and labour issues in small-scale mining* – that focuses on some of the major issues within this activity. The first chapter sets the scene, putting small-scale mining in context in terms of production and employment, and addresses the issues in general terms. The subsequent chapters on occupational health and safety, women in mining and child labour illustrate some of the problems that exist and are being dealt with. Although the report mainly deals with social and labour issues at a more general level, use of mercury in small-scale mining is emphasized as a major problem within gold production. The report gives examples of how some of the issues are being and might be addressed. By discussing and clarifying the role of governments, the social partners and the ILO, it is hoped that the profile of small-scale mining within the ILO and among the social partners will be raised, leading to increased assistance in providing the means for small-scale mining to ensure safe and productive employment. This will inevitably contribute to the achievement of higher productivity and remuneration, improved working conditions and health and safety, better resource management and lessening of its environmental impact.

9.4.3 International Programme on Chemical Safety (IPCS)

937. The International Programme on Chemical Safety, IPCS, was established in 1980 as a co-operative programme of WHO, ILO and UNEP to provide internationally evaluated assessments of the risks caused by chemicals to human health and the environment, which countries may use in developing their own chemical safety measures and to strengthen national capabilities for preventing and treating harmful effects of chemicals and for managing the health aspects of chemical emergencies.

938. The evaluation of chemical risks to human health and the environment, and the preparation and publication of documents on the health and environmental risks of specific chemicals, is a major focus of IPCS work. The documents, prepared by internationally renowned experts and peer-reviewed by leading independent experts, are designed to be used by readers with different levels of technical expertise and include the following:

- Environmental Health Criteria (EHC) monographs - extensive documents designed for scientific experts responsible for the evaluation of risks posed by chemicals;
- Concise International Chemical Assessment Documents (CICADs) - concise documents that provide summaries of the relevant scientific information concerning the potential effects of chemicals on human health and/or the environment;
- Health and Safety Guides (HSG) - provide concise information for decision-makers on risks from exposure to chemicals, with practical advise on medical and administrative issues; and
- International Chemical Safety Cards (ICSC) - summarize health and safety information for individuals at the workplace, including symptoms of poisoning, safety procedures and first aid;
- Data Sheets on Pesticides - contain basic information for their safe use.

939. IPCS has published the following documents relevant to mercury:

- EHC 1 (1976): Mercury;
- EHC 86 (1989); Mercury - environmental aspects;
- EHC 101 (1990); Methylmercury;
- EHC 118 (1991); Mercury, inorganic.

940. In addition, the Joint FAO/WHO Expert Group on Food Additives and Contaminants evaluated methylmercury in 1999, and the evaluation was published in the *WHO Technical Report series* 896, pp 87-93 (WHO, 2000). These documents are all available on the IPCS website at http://www.who.int/pcs/pcs_pubs.html. IPCS has recently re-evaluated the health and environmental hazards from elemental mercury and inorganic mercury compounds in the CICAD-series (WHO/IPCS, 2002). This document includes an evaluation of the hazards and risks from exposure to mercury from amalgam fillings in teeth and will be available in print in the near future at the website mentioned above.

9.4.4 The Organization of Economic Co-operation and Development (OECD)

941. The Organization of Economic Co-operation and Development, OECD, is an intergovernmental organisation bringing together 30 Member countries in a forum for governments to compare experience, discuss issues of concern, and seek and design solutions including, where appropriate, common or co-operative actions. The Member countries (from Europe, North America, Asia and the Pacific) share a commitment to the market economy, pluralistic democracy, and respect for human rights. The OECD's fundamental mission is to enable Members to consult and co-operate with each other so as to achieve the highest possible sustainable economic growth, improve the economic and social well-being of their populations, and contribute to development worldwide.

942. The Environment Programme, one of many areas of work within the OECD, addresses a wide range of issues of concern to Member countries. Of particular interest to this publication is the Environment, Health and Safety Programme, which includes the Chemicals Programme, as well as work on pesticides, chemical accidents, harmonisation of regulatory oversight in biotechnology, Pollutant Release and Transfer Registers and food safety. The Chemical Programmes main activities are to:

- Assist Member countries in identifying, preventing and managing the risks of chemicals;
- Promote the public's right to know about the potential risks of chemicals;
- Prevent unnecessary distortions in the trade of chemicals;
- Facilitate the optimal use of national resources available in government and industry for chemicals management;
- Assist Member countries in working towards an integrated chemicals management approach that incorporates economic, social and environmental policy considerations, in support of achieving the objectives of sustainable development, and in particular those of UNCED's Agenda 21, Chapter 19;
- Facilitate that globalisation of the chemical industry leads to positive impacts on human health and the environment in OECD Member countries, as well as in non-OECD countries; and
- Promote the development of, and implementation in, Member countries of new and innovative technologies, policies and practices that prevent pollution from the manufacture, transport, use and disposal of chemicals.

943. In 1973, the OECD Council adopted *Recommendation C (73) 172/Final on Measures to Reduce all Man-Made Emissions of Mercury to the Environment*, recommending all member countries to adopt measures to reduce all man-made releases of mercury to the environment to the lowest possible levels. The immediate targets set were elimination of alkyl-mercury compounds in agriculture, elimination of mercury compounds from use in the pulp and paper industry and the maximum possible reduction of discharges of mercury from mercury chlor-alkali plants. The Council also invited member countries to report on the quantities of mercury being used in the agricultural and industrial sectors and on total national consumption.

944. In 1993, Denmark hosted a workshop on risk reduction of mercury to collect relevant information and identify possible future risk management activities. Based on the responses to a questionnaire, and the material discussed at the workshop, a monograph on mercury was published in 1994, entitled *Risk Reduction Monograph No. 4: Mercury – Background and National Experience with Reducing Risk.* It provides a summary of information regarding releases of mercury to the environment, the ensuing environmental and human exposures and the way OECD Member countries perceived the risks associated with exposure to mercury and describes the actions Member countries and industry had taken, or contemplated taking to reduce risks associated with exposure to mercury. The document provides a "snapshot" of the most recent thinking concerning the different activities within the field of mercury consumption and pollution. It may assist in evaluating the effectiveness of national risk reduction strategies for mercury by identifying common trends in setting criteria, standards or national policies.

945. In 1996, OECD member countries agreed to cease further work on mercury within the OECD context.

9.4.5 United Nations Environment Programme - The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (Global Programme of Action)

946. The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) was adopted in November 1995 at an intergovernmental conference in Washington, DC. The 108 governments and European Commission declared their commitment to preserve the marine environment and called upon UNEP, the World Bank, UNDP, regional development banks and all agencies within the UN system to support and strengthen regional structures for the protection of the marine environment. UNEP was asked to lead the co-ordination effort and establish a GPA Co-ordination Office.

947. The GPA seeks to prevent the degradation of the marine environment from land-based activities by facilitating realisation of the duty of States to preserve and protect the marine environment. It is designed to be a source of conceptual and practical guidance to be drawn upon by national and regional authorities in devising and implementing sustained action to prevent, reduce, control and/or eliminate marine degradation from land-based activities. Specifically, the GPA aims to facilitate identification and assessment of problems; establishment of priorities for action; setting of management objectives for priority problems; identification, evaluation and selection of strategies and measures; and development of criteria for evaluating effectiveness of strategies and measures.

948. The programme has a special section for recommendations regarding heavy metals, including mercury. The objective/proposed target is to reduce and/or eliminate anthropogenic emissions and discharges in order to prevent, reduce and eliminate pollution caused by heavy metals. Although there are no specific goals set with regards to mercury, the programme provides detailed guidance on possible/proposed steps in the pursuit of reduced environmental effects from heavy metals and other pollutants. Proposed activities at national, region and international level include, among others:

- Establishment of assessment and monitoring programmes;
- Development of programmes for emission reductions (respecting the precautionary principle, best available techniques (BAT), best environmental practice (BEP) and integrated pollution prevention and control (IPPC));
- Establishment of waste management schemes;
- Promotion of cleaner technology and emission control technology;
- Implementation of awareness campaigns and information activities;
- Formation and strengthening of national and international co-operation; and
- Provision of financial and technical assistance to countries with special needs.

949. The implementation of the GPA is primarily the task of Governments, in close partnership with all stakeholders. UNEP and its partners facilitate and assist Governments in their tasks.

9.4.6 United Nations Industrial Development Organization (UNIDO)

950. The United Nations Industrial Development Organization, UNIDO, was created in 1967 and, since 1985, has been a specialised agency of the United Nations dedicated to promoting sustainable industrial development in developing countries and countries in economic transition. UNIDO brings together representatives of government, industry and the public and private sector, providing a forum for consideration of issues related to sustainable development. UNIDO is also involved in work related to environmental management in various industrial sectors and related to monitoring, treatment, recycling, and disposal of toxic and hazardous chemical wastes and remediation of contaminated sites.

951. Since 1990, UNIDO has been involved in identifying measures to address the complex problems related to artisanal gold mining. It has implemented a number of projects designed to replace high mercury consuming and discharging processes with cost-effective environmentally safe and high-yield gold extraction alternatives that sharply reduce or eliminate the use and discharge of mercury. Projects

providing assistance in assessing and reducing mercury pollution emanating from artisanal gold mining have been carried out in Ghana and the Mindanao area in the Philippines.

952. The Global Environment Facility (GEF) which funds projects in developing countries that address issues such as climate change, biological diversity and international waters, has allocated USA$ 350,000 to UNIDO for formulating a global action plan for countries located in key transboundary river/lake basins affecting international waters with mercury from artisanal mining. Six countries from three continents will participate: Brazil (Amazon River), Lao People's Democratic Republic (Mekong River), Indonesia (marine environment, especially Java Sea), Sudan (Nile River), Tanzania (Lake Victoria) and Zimbabwe (Zambezi River). The UNIDO-GEF global action plan will identify what steps should be taken in order to remove barriers to the introduction of cleaner artisanal gold mining technologies.

953. As a follow-up, a full project has been developed to help the governments of six countries, namely Brazil, Indonesia, Lao PDR, Sudan, Tanzania and Zimbabwe, where artisanal gold mining activities threaten international waters with mercury releases. The long-term objective of the project is to minimize negative environmental impacts from the artisanal mining sector. This will be achieved by assisting the recipient countries to promulgate a legal framework and design appropriate regulations for the mining sector, and develop institutional structures. In particular, the project will develop the capabilities of recipient countries to assess the extent of mercury pollution from current activities, manage the regulatory mechanisms, and introduce cleaner gold mining and extraction technologies that minimize or eliminate mercury releases. Similar individual, projects are being developed within the context of UNIDO's integrated country programmes in Chad, Ghana, Indonesia, Mali, Mozambique, Niger, Philippines, Venezuela, and Vietnam.

9.4.7 The World Bank Group

954. Founded in 1944, the World Bank Group is one of the world's largest sources of development assistance. The Bank, which provided USA$ 17.3 billion in loans to its client countries in fiscal year 2001, is now working in more than 100 developing economies, bringing a mix of finance and ideas to improve living standards and eliminate the worst forms of poverty. For each of its clients, the Bank works with government agencies, nongovernmental organizations, and the private sector to formulate assistance strategies and increase understanding of development issues.

955. The World Bank is pursuing new initiatives to ensure that the benefits of incorporating sustainability into all its activities are felt on a global scale and for the long-term. The World Bank’s Board approved a new Environment Strategy on July 17, 2001, which places emphasis on developing country priorities. The objectives of the strategy are i*mproving the quality of life* — people’s health, livelihood and vulnerability affected by environmental conditions; i*mproving the quality of growth* — by supporting policy, regulatory, and institutional frameworks for sustainable environmental management and by promoting sustainable private development; and p*rotecting the quality of the regional and global commons* such as climate change, forests, water resources and biodiversity.

956. The World Bank’s portfolio of projects with clear environmental objectives currently amounts to USA$ 16 billion. Some of the activities of relevance to mercury are:

> **Pollution prevention and abatement within industrial activities -** emphasizing integrated environmental management, rather than just pollution control and using a broad mix of incentives and pressures to achieve sustainable environmental improvements. The Bank has also published a Pollution Prevention and Abatement Handbook (1998) that can be accessed through their web site.
>
> **Environmentally sustainable artisanal and Small-Scale Mining –** promoting the engagement of relevant communities and groups through information and education, while using the legal and regulatory framework, as well as direct agreements with the mining company, to establish appropriate environmental performance as well as acceptable work conditions. Key to mitigating environmental risks is setting and monitoring appropriate standards.

957. Some projects currently under implementation are:

- The Liao River Basin Project (China) will assist in the environmental recovery of, and enhance water quality management for an integrated river basin management approach, in the Liaoning Province. One of the components of the project is construction of a chlorine production facility, based on modern ion membrane cell technology. Remedial measures to recover mercury will be taken into account and an action plan for demolition of the mercury electrolysis facility will be developed.

- The Urgent Environmental Investment Project (Azerbaijan) aims to direct action in four areas identified in the Azeri National Environmental Action Plan, which are critically important for Azerbaijan's environment and economy. The project has 5 components; component 2 demonstrates mercury cleanup technologies and procedures by decontaminating one heavily polluted area. It tests pilot-scale sludge treatment; develops and applies a low-technology method for mercury recovery; transports wastes; constructs a safe, new landfill; designs and implements a monitoring programme for mercury releases; and does a follow-up assessment.

- The Mining Sector Reform Project (Madagascar) will (a) complete sector reforms aimed at establishing an enabling environment to both promote foreign direct investment in mining and integrate small-scale and artisinal activities into the formal economy; (b) build institutional capacity to effectively enforce laws and regulations, administer mining titles, monitor sector developments, and make geological information available to potential investors; (c) establish capacity in the country, by means of pilot projects, to identify and address environmental as well as social impacts from mining; and (d) identify and adopt appropriate mechanisms to facilitate development of small-scale mines and to improve the social, welfare, health, and environmental conditions of artisinal miners.

958. The World Bank also hosted a seminal meeting on small-scale and artisanal mining in 1995. One of the key conclusions of this conference was the need for integrated solutions to the problems of the sector and improved cooperation between the various institutions. Further meetings respectively convened by UNIDO and ILO involving bi/multilateral institutions reiterated the need for a coordinated approach towards the artisanal and small-scale mining sector if significant progress to be made. In response to this, the World Bank developed a proposal to establish a Consultative Group for Artisanal and Small Scale Mining (CASM). The goal is to establish a forum that would provide a coordinated approach to assessing and addressing some of the problems with this sub-sector as opposed to a piece-meal approach. CASM would be responsible for developing policy guidelines, providing advice, disseminating best practices and experiences, raising funds and project/programme implementation. It would examine and fund proposals for assistance to the artisanal and small-scale mining sectors according to pre-established criteria. In September 1999, a forum was held bringing together bi- and multilateral donors, private companies, NGOs, and knowledgeable experts to explore the possibility of establishing this CASM. The Bank is currently working, in consultation with the participants, to convert this proposal into reality.

9.4.8 Main references for this section

959. The main references used in this section are, in addition to those submitted by the organizations:

- IARC website - http://www.iarc.fr/
- ILO web site – http://www.ilo.org,
  ILO, Geneva, Switzerland (1999): Social and labour issues in small-scale mining - http://www.ilo.org/public/english/dialogue/sector/techmeet/tmssm99/tmssmr.htm;
- IPCS web site - http://www.who.int/pcs/index.htm;
- JECFA website - http://www.who.int/pcs/jecfa/JECFA_publications.htm
- OECD web site – http://www.oecd.org;
- UNEP Global Programme of Action web site - http://www.gpa.unep.org;
- UNIDO website – http://www.unido.org.
- World Bank website - http://www.worldbank.org/html/fpd/mining/default.html

9.5 Sub-regional and regional initiatives

960. Finally, a number of governments have found it beneficial to cooperate across national borders in order to address the adverse impacts of mercury on health and the environment in a specific sub-region or region. An overview of such sub-regional and regional initiatives identified in this project that have activities relevant to mercury are given in table 9.5. In the following sections are presented summaries of those initiatives and their relevance to mercury.

Table 9.5 - Overview of sub-regional and regional initiatives addressing the adverse impacts of mercury on health and the environment.

Section	Sub-regional or regional initiative	Geographic coverage	Initiative's relevance to mercury	Types of measures addressing mercury set out in the initiative
9.5.1	Arctic Council Action Plan (ACAP)	Arctic region (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and United States of America)	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, co-operative release reduction projects, information, monitoring
9.5.2	Great Lakes Binational Toxics Strategy	Canada and the United States of America	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, information, capacity building
9.5.3	New England Governors/ Eastern Canada Premiers Mercury Action Plan	Individual New England States (United States) and Eastern Canadian Provinces (Canada)	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, information, capacity building, education and outreach programmes
9.5.4	Nordic Environmental Action Programme	Nordic region (Denmark, Finland, Iceland, Norway and Sweden and Greenland, Faroe Islands and Åland)	Addresses heavy metals, including mercury	Goal definition, information, capacity building
9.5.5	North American Regional Action Plan on Mercury	North American region (Canada, Mexico and United States of America)	Addresses mercury and mercury compounds in releases, products, wastes, etc.	Goal definition, information, capacity building
9.5.6	North Sea Conferences	North Sea (Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, Switzerland, United Kingdom, European Commission)	Addresses heavy metals, including mercury	Goal definition, information
9.5.7	Coordinating Body on the Sea of East Asia – UNEP/GEF project on reversing environmental degradation trends in the South China Sea and Gulf of Thailand	South China Sea and Gulf of Thailand (Cambodia, China, Indonesia, Malaysia, Philippines, Thailand and Vietnam)	Addresses heavy metals including mercury contamination in sea water, sediment and marine organisms	Information, source reduction

9.5.1 Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP)

961. The Arctic Council, established on 19 September 1996, is a high-level intergovernmental forum that provides a mechanism to address the common concerns and challenges faced by the Arctic governments and the people of the Arctic. Its member countries are those bordering the Arctic area: Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States of America. The Association of Indigenous Minorities of the North, Siberia and the Far East of the Russian Federation, the Inuit Circumpolar Conference, the Saami Council, the Aleutian International Association, Arctic Atha-

baskan Council and Gwich'in Council International are permanent participants in the Council. The Council meets at the ministerial level biennially.

962. The main activities of the Council focus on the protection of the Arctic environment and sustainable development as a means of improving the economic, social and cultural well-being of the north. In 1991, the Council launched its Arctic Environmental Protection Strategy, where member countries are committed to:

- Cooperating in scientific research to specify sources, pathways, sinks and effects of pollution, in particular, oil, acidification, persistent organic contaminants, radioactivity, noise and heavy metals as well as sharing of these data;
- Assessing potential environmental impacts of development activities; and
- Full implementation and consideration of further measures to control pollutants and reduce their adverse effects to the Arctic environment.

963. The Arctic Monitoring and Assessment Programme, AMAP, was established in 1991 to implement components of the Arctic Environmental Protection Strategy. AMAP's objective is "providing reliable and sufficient information on the status of, and threats to, the Arctic environment, and providing scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants".

964. In June 1997, AMAP report *"Arctic Pollution Issues: A State of the Arctic Environment Report"* was submitted to Arctic ministers under the Arctic Environmental Protection Strategy. This comprehensive report constitutes a compilation of current knowledge about the Arctic region, an evaluation of this information in relation to agreed criteria of environmental quality, and a statement of the prevailing conditions in the area. It contains a separate chapter on heavy metals, including mercury, describing the concentrations found in the Arctic area in terrestrial, freshwater and marine ecosystems.

965. The ministers agreed to a number of actions in response to the findings of AMAP. These included increasing efforts to limit and reduce releases of pollutants into the environment, and the promotion of international co-operation in order to reduce the identified pollution risks. In addition, an Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP) was developed. In the plan a number of pollutants of special concern for the Arctic region – including mercury – have been prioritised for further action.

966. For mercury the planned activities include identification and quantification of major point sources of mercury in all member countries, with the subsequent aim of implementing concrete emission reduction pilot projects for a few emissions sources that would serve as examples of effective mercury reduction initiatives.

9.5.2 The Great Lakes Binational Toxics Strategy

967. The Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes Basin, known as the Great Lakes Binational Toxics Strategy, provides a framework for actions to reduce or eliminate persistent toxic substances, especially those which bio-accumulate, from the Great Lakes Basin. The Strategy was developed jointly by Canada and the United States in 1996 and 1997 and was signed 7 April 1997.

968. The purpose of this binational strategy is to set forth a collaborative process by which Canada and the USA will work towards the goal of virtual elimination of persistent toxic substances resulting from human activity, particularly those which bioaccumulate, from the Great Lakes basin, so as to protect and ensure the health and integrity of the Great Lakes ecosystem. The Strategy establishes reduction challenges for an initial list of persistent toxic substances targeted for virtual elimination: aldrin/dieldrin, benzo(a)pyrene, chlordane, DDT, hexachlorobenzene, alkyl-lead, mercury and compounds, mirex, octachlorostyrene, PCBs, dioxins and furans, and toxaphene.

969. Although both Canada and the United States also have domestic virtual elimination strategies, a coordinated strategy was deemed necessary for the greatest reduction in toxic substances throughout the Great Lakes Basin. Recognizing the long-term nature of virtual elimination, the Strategy provides the framework for actions to achieve quantifiable reduction "challenges" in the timeframe 1997 to 2006 for specific toxic substances. Flexibility is provided in the Strategy to allow for the revision of challenges, timeframes and the list of substances. The challenges for mercury set in the strategy are as follows (considered as an interim reduction targets, to be revised, if warranted):

970. USA Challenge: Seek by 2006, a 50 percent reduction nationally in the deliberate use of mercury and a 50 percent reduction in the release of mercury from sources resulting from human activity. The release challenge will apply to the aggregate of releases to the air nationwide and of releases to the water within the Great Lakes Basin.

971. Canadian Challenge: Seek by 2006, a 90 percent reduction in the release of mercury, or where warranted the use of mercury, from polluting sources resulting from human activity in the Great Lakes Basin.

9.5.3 New England Governors/Eastern Canada Premiers Mercury Action Plan

972. In June 1998, the Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP) adopted the landmark Mercury Action Plan, which specifies actions to protect the region's citizens and its environment from the toxin mercury. The Plan provides the New England states and Eastern Canadian provinces with a coordinated and powerful set of tools to reduce anthropogenic releases of mercury in the region and remove mercury from the region's waste streams.

973. The Mercury Action Plan sets a long-term goal of virtual elimination of anthropogenic mercury emissions in the region. The plan also established an intermediate goal committing to actions to reduce regional mercury emissions by 50 percent by 2003. This intermediate goal has provided an important benchmark to motivate and track progress towards virtual elimination. In a recent development, the NEG/ECP in August 2001 adopted a second interim goal calling for 75 percent reduction of regional mercury releases by 2010. The new reduction goal should be challenging, but also feasible to achieve.

974. Since the adoption of the Plan, representatives of state and provincial environmental agencies on the Mercury Task Force, in conjunction with partnering organizations including the USA Environmental Protection Agency, Environment Canada, Northeast States for Coordinated Air Use Management (NESCAUM), the Northeast Waste Management Officials' Association (NEWMOA) and the Commission for Environmental Cooperation (CEC), have aggressively implemented the spirit and commitments of the Plan. As a result, the region is on target to meet and will likely exceed the 50 percent reduction target for 2003.

975. In the outreach and education area the jurisdictions have focused on such activities as increasing public awareness of fish consumption advisories, particularly with respect to sensitive populations; working with the healthcare sector, including hospitals and dental offices, to reduce mercury releases and use; increasing local efforts to divert mercury from the waste stream through source separation and recycling; and working with schools to eliminate mercury hazards in the classroom. Pollution prevention activities have focused on significant efforts to address the mercury content of consumer and commercial products through implementation of state legislation and through development of the country-wide standards. Mercury collection programmes and thermometer exchanges have also contributed to successful efforts to reduce the mercury burden in the solid waste stream as well as educate the public about mercury.

9.5.4 The Nordic Environmental Action Programme

976. Official Nordic co-operation is channelled through two organisations: the Nordic Council and the Nordic Council of Ministers. The Nordic Council, formed in 1952, is the forum for inter-parliamentary co-operation. The Nordic Council of Ministers, formed in 1971, is the forum for inter-

governmental co-operation. Five countries – Denmark, Finland, Iceland, Norway and Sweden - and three autonomous regions - Greenland, Faroe Island and Åland – participate.

977. Most of the Nordic ministers for specific policy areas meet their Nordic counterparts twice a year – the Council of Ministers for the Environment sets policies with regard to environmental cooperation. For a number of years, Nordic environmental cooperation has been based on an environmental strategy with a series of objectives. The Nordic Environmental Action Programme 2001-2004, which replaces the Nordic Environmental Strategy 1996-2000, is a political, targeted, result-orientated steering instrument establishing environmental priorities within the framework of Nordic cooperation in the field of nature and the environment. It entered into force on 1 January 2001. The action programme follows up on the Nordic environmental commitments contained in the Nordic strategy, "Sustainable Development - New Bearings for the Nordic Region", and in an active manner, the programme takes up horizontal cooperation to achieve integration of environmental considerations into all sectors.

978. The strategy sets the following general objective with regards to chemicals:

> *"The use of chemicals must not entail any risk of negative impacts on human health and the environment, and discharges of chemicals constituting a threat to human health and the environment must be discontinued within one generation (25 years)."*

979. In their cooperation, the Nordic countries will work to ensure that the generation objectives set under the OSPAR and Helsinki Conventions are made operational, that regulations and strategies leading to a higher level of protection within the European Union/European Economic Agreement are adopted and international, legally binding agreements which, to the widest possible extent, impose a ban or very stringent thresholds for the use and discharge of chemicals hazardous to human health and the environment are adopted. One of the planned activities, relevant to mercury, states that the Nordic countries will take action *"to limit substances other than POPs (heavy metals) at global level through international agreements".*

9.5.5 North American Regional Action Plan on Mercury

980. The Commission for Environmental Cooperation (CEC) is an international organization created by Canada, Mexico and the United States of America under the North American Agreement on Environmental Cooperation (NAAEC). The CEC was established to address regional environmental concerns, help prevent potential trade and environmental conflicts, and to promote the effective enforcement of environmental law. The Agreement complements the environmental provisions of the North American Free Trade Agreement (NAFTA). The Council, the governing body of the CEC, is composed of the environment ministers (or the equivalent) of each country. It meets at least once a year to discuss CEC programmes and activities.

981. The Commission provided the mechanism for the three member countries to negotiate an agreement, Council Regulation #95-5 on the Sound Management of Chemicals, which was agreed to on 13 October 1995. The resolution sets out a framework, together with specific commitments, to work collaboratively in addressing the sound management of chemicals in the region. A Working Group was established to work with the CEC to implement the decisions and commitments made in the resolution. Since then, four North American Regional Action Plans, on DDT, chlordane, PCBs and mercury, have been developed and are now at various stages of implementation.

982. The ultimate goal of the Action Plan on Mercury is to achieve a reduction in the anthropogenic releases of mercury to the North American environment through appropriate national and international initiatives, to amounts that can be attributed to naturally occurring levels and fluxes. The Parties intent is to obtain this goal by seeking to reduce mercury releases from human activities, develop enhanced capacity to measure and manage mercury, asses impact and communicate concerns, establish an equitable implementation and compliance protocol and promote continued responsible mercury management initiatives on behalf of governments, industry and citizens through regulatory and voluntary/non-regulatory mercury management actions.

983. The plan sets out detailed recommendations for reducing emissions and releases of mercury from a large number of sources and activities. Examples of some of the specific recommendations made in the Action Plan are:

- Promoting **life cycle management practises** (tracking exports and imports, promoting recognized environmental management systems (such as ISO 14.000);
- Encouraging the timely adoption of **5 kilogram reporting threshold** for facilities that manufacture, process or use mercury on an annual basis through national pollutant release and transfer registers;
- Encouraging **substitution or phase-out of mercury in products or processes**. Where no substitutes available, promoting the use of recycled or recovered mercury;
- Encouraging development of **substitutes in the automotive vehicle industry** both for new and existing vehicles;
- Promoting measures that **reduce or eliminate the use of mercury** in other sectors such as battery manufacturing sector, electrical switches and relays sector, lamp manufacturing sector, health and dental care sector, cultural and artisanal uses and analytical, testing, measurement, calibration and education sector;
- Managing atmospheric emissions of mercury (goal of 50 percent reduction nationally in mercury emissions by 2006 from existing major stationary sources based on 1990 or equivalent emissions inventories);
- Monitoring the industry-developed voluntary/non-regulatory programme to **reduce mercury usage in the mercury cell chlor-alkali industry by 50 percent to 80 metric tons, by the year 2005** and ensuring that new chlor-alkali facilities constructed after 2000 meet a limit value of 0.01 g Hg/metric ton chlorine production capacity, or, where warranted, ban the mercury-cell process;
- Preventing **mercury in products and process waste** from being released directly to the environment, by encouraging efficient waste collection and preventing mercury in products and process waste from being mixed with less hazardous waste in the general waste stream, by encouraging separate collection and treatment;
- Considering development of an initiative to **promote mercury retirement** whereby emission sources that meet required standards but continue to emit residual amounts of mercury are able to counterbalance their residual emissions by removing and retiring an equal or greater amount of mercury from the North American pool;
- Encouraging development and use of effective mercury **waste-stabilization and disposal techniques** and methods;
- Developing consistent/comparable mercury-related data;
- Promoting collaborative research programmes and atmospheric modelling work.

984. Although the regional Action Plans under the Sound Management of Chemicals initiative are not legally binding upon any one or all of the Parties to the North American Agreement on Environmental Cooperation, there is a strong national commitment by each member country to ensure that the Action Plan on mercury results in significant reductions of mercury contamination to the environment. The implementation of the Action Plan will be ensured through the oversight of an Implementation Task Force.

9.5.6 The North Sea Conferences

985. The First International Conference on the Protection of the North Sea was held in Bremen 1984. The aim was to provide political impetus for the intensification of the work within relevant international bodies, and to ensure more efficient implementation of the existing international rules related to the marine environment in all North Sea States. It was thought that a political declaration from a North Sea perspective, would stimulate and bring further ongoing work within the existing international

conventions, such as the Oslo Convention on dumping at sea, the Paris Convention on pollution from land-based sources and the IMO Convention on shipping issues.

986. The Bremen Conference initiated a continuous process where focus is put on the protection of the North Sea at regular Ministerial Conferences. The Bremen Conference in 1984 was followed by the London Conference in 1987, the Hague Conference in 1990, the Esbjerg Conference in 1995 and the most recent Conference in Bergen in March 2002. The North Sea Conferences are political events where the ministers responsible for the protection of the environment meet for a broad and comprehensive assessment of the measures needed to protect the North Sea environment. The decisions of Ministers as recorded in the Ministerial Declarations are political commitments that have played an important role in influencing legally binding environmental management decisions both nationally and within the framework of competent international bodies. Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden, Switzerland, United Kingdom and European Commission take part in this cooperation.

987. The North Sea Conferences address a wide range of issues as regards the protection of the North Sea such as species and habitats issues, pollution by hazardous substances and nutrients, radioactive substances and pollution from ships and offshore installations. Due to the concern about the impact of fisheries on the commercially important fish stocks, on other fish stocks and on the marine ecosystem in general, fishery activities were introduced as a new issue during the 1990's.

988. In 1990, ambitious targets were agreed to reduce inputs of 36 hazardous substances, including mercury, by 50 percent and for substances that cause a major threat to reduce inputs by 70 percent. The long-term target agreed at the Esbjerg Conference in 1995 of continuously reducing discharges, emissions and losses of hazardous substances, thereby moving towards the target of their cessation within one generation, has now been adopted by the OSPAR Convention and has thus become legally binding. According to the Progress report for the 5th Conference in Bergen in March 2002, all the countries participating in the North Sea cooperation have met the reduction target of 50 percent for mercury, lead and cadmium releases to air and water. For mercury, the reductions in eight countries total at least 70 percent and one country has reported a 64 percent reduction.

9.5.7 Coordinating Body on the Sea of East Asia – UNEP/GEF project on reversing environmental degradation trends in the South China Sea and Gulf of Thailand

989. The UNEP/GEF project on "Reversing environmental degradation trends in the South China Sea and Gulf of Thailand" is a regional project for the East Asian seas. The project was approved at the 15th Meeting of the Coordinating Body on the Sea of East Asia (COBSEA) and is funded by the Global Environment Facility (GEF). This significant GEF project (32 million USA$) represents the first attempt to develop regionally co-ordinated programmes of action designed to reverse environmental degradation particularly in the area of coastal habitat degradation and loss, halt land-based pollution and address the issue of fisheries over-exploitation. The participating countries include Cambodia, China, Indonesia, Malaysia, Philippines, Thailand and Vietnam. The Project Steering Committee, as the supreme decision-making body of the project, is composed solely of representatives of the countries participating in the project. UNEP, through its East Asia Seas Regional Coordination Unit acts as the Secretariat of the Committee. The project will be implemented during 5 years from 2001.

990. The overall goals of this project are to create an environment at the regional level, in which collaboration and partnership in addressing environmental problems of the South China Sea and Gulf of Thailand, between all stakeholders and at all levels, is fostered and encouraged; and to enhance the capacity of the participating governments to integrate environmental considerations into national development planning. Major outcomes will include a Strategic Action Programme including a targeted and costed programme of action and framework for regional co-operation in the management of the environment of the South China Sea and Gulf of Thailand; national and regional management plans for specific habitats and issues; pilot activities relating to alternative remedial actions to address priority transboundary pollutants and adopted water quality objectives and standards; a regional strategy for achiev-

ing long term benefits from continued sustainable use of the resources of the South China Sea and Gulf of Thailand; and demonstration management activities at sites of regional and global significance.

9.5.8 Main references for this section

991. The main references used in this section are, in addition to those submitted by the organizations:

- Arctic Council website - http://www.arctic-council.org; AMAP website - http://www.amap.no/;
- US EPA web site: Binational Toxics Strategy - http://www.epa.gov/glnpo/bns/;
- Commonwealth of Massachusetts' submission – http://www.chem.unep.ch/mercury/gov-sub/sub18gov.pdf; NEG/ECP web site - http://www.cmp.ca/toc.htm;
- Nordic Council website - http://www.norden.org/start/start.asp;
- CEC web site - http://www.cec.org.
- North Sea Conference website - http://odin.dep.no/md/nsc/
- UNEP East Asia Seas Regional Coordination Unit website - http://www.unepscs.org.

10 Data and information gaps

992. This chapter is intended to characterise the main categories of data gaps identified for improved risk assessment and risk management with regard to mercury. As such it does not attempt to give a full list of detailed data gaps in the different fields of research.

10.1 National research and information needs

993. A number of countries have in their submissions to UNEP expressed a need for establishing or improving their national "database" (i.e. knowledge of and information on uses and emissions, sources of releases, levels in the environment and prevention and control options) on mercury and mercury compounds. Although the situation varies from country to country, there seems to be a general need for information relevant to the various elements of an environmental management strategy for mercury. Also countries with a longer tradition of environmental management of mercury have expressed the need to continue to expand their knowledge base on mercury to improve risk assessment and ensure effective risk management. Some of the needs include, among others:

- Inventories of national use, consumption and environmental releases of mercury;
- Monitoring of current levels of mercury in various media (such as air, air deposition, surface water) and biota (such as fish, wildlife and humans) and assessment of the impacts of mercury on humans and ecosystems, including impacts from cumulative exposures to different mercury forms;
- Information on transport, transformation, cycling, and fate of mercury in various compartments;
- Data and evaluation tools for human and ecological risk assessments;
- Knowledge and information on possible prevention and reduction measures relevant to the national situation;
- Public awareness-raising on the potential adverse impacts of mercury and proper handling and waste management practises;
- Appropriate tools and facilities for accessing existing information relevant to mercury and mercury compounds at national, regional and international levels;
- Capacity building and physical infrastructure for safe management of hazardous substances, including mercury and mercury compounds, as well as training of personnel handling such hazardous substances;
- Information on the commerce and trade of mercury and mercury-containing materials.

International information exchange and national efforts to collect information

994. In principle, some parts of this information might be exchanged nationally, regionally or internationally, as its relevance is often universal, however, it might need to be "translated" into the context of the individual country's framework of traditions, economic and industrial activities and political reality. This, in itself, demands a substantial degree of priority, knowledge and funding.

995. The assessment process undertaken by UNEP through Governing Council decision 21/5 and the data collected and presented in this connection (reports, documents, web-page) in itself contributes to such information exchange – other additional information exchange activities might also be considered. No doubt, large amounts of basic knowledge on mercury have been generated, and progressively more information is becoming globally available thanks to national, regional and international efforts. Furthermore, the speed of the information exchange is increasing as more and more information on mercury and other hazardous substance becomes available via the Internet.

996. Other parts of the information are country specific and would require national efforts to research, collect and process the information necessary to establish national action plans/strategies on mercury within the context of their national environmental management scheme.

997. A number of countries have developed strategies to promote research and information generation activities to fill identified information gaps or generate further information to support their mercury risk assessment and management activities. A few examples include the Mercury Research Strategy issued in September 2000 by the US EPA (sub-5-gov) and the COMERN (Collaborative Mercury Research Network) research programme on the impacts of atmospheric mercury deposition on large scale ecosystems in Canada, supported by the Canadian government (sub-5-ngo). A number of national and regional mercury action plans also contain sections describing concrete activities to fill data and information gaps.

10.2 Data gaps of a general, global character

998. In addition, although mercury is probably among the best-studied environmental toxicants, there are data gaps in the basic understanding of a number of general, global issues relevant to mercury.

999. Based on submitted information and the compilation and evaluation hereof, a possible division of current data gaps of global relevance on mercury could be as follows (not in order of priority):

- Understanding and quantification of the **natural mechanisms affecting the fate of mercury** in the environment, such as mobilisation, transformation, transports and intake. In other words, the pathways of mercury in the environment, and from the environment to humans.
- Understanding and quantification – in a global perspective – of the **human conduct in relation to mercury releases**, and the resulting human contributions to the local, regional and global mercury burden. In other words, the pathways of mercury from humans to the environment.
- Understanding of how and to what degree humans, ecosystems and wildlife are **adversely affected by the current mercury levels** found in the local, regional and global environment. In other words, the possible effects, number affected, and the magnitude and severeness in those affected.

Basic understanding

1000. A basic understanding has been established for all three categories mentioned above, based on about half a century's extensive research on the impacts and pathways of mercury. However, in a number of areas, further research is needed to provide new information to improve environmental modelling assessments and modern decision-making tools.

Quantification of origins, pathways and impacts of mercury

1001. In order to manage environmental toxicants like mercury efficiently and cost-effectively, a substantial level of quantification of origins, pathways and impacts is necessary. The question of which level of certainty of evidence is considered required as a basis for abatement actions is, however, basically political – a set of priorities in the span of public health, environmental quality and socio-economic possibilities. The traditions and political priorities on these aspects vary among countries and regions, and develop over time.

1002. However, as an example, Canada expressed in their comments to the first draft of this report (comm-24-gov):

> "…, there are numerous areas where additional knowledge is required, for example in the areas of biochemistry, atmospheric sciences, hydrology, toxicology/epidemiology, monitoring strategies for mercury levels in biota, and the collection of information on mercury levels in fossil fuels. However, while it is important to be aware of outstanding questions, the existing evidence clearly dem-

> onstrates that there are risks to the environment and human health associated with mercury exposure. Therefore, it is not realistic to delay the process of the assessment and options development until we have all the answers."

Summary of identified data gaps

1003. The following sections provide a summary of the types of data gaps mentioned in submissions and comments to the first draft of this report, as well as gaps identified in the preparation of this report. For more details, see references given below.

10.2.1 Examples of data gaps on natural mechanisms affecting the fate of mercury

- Further studies of natural emissions of mercury would be useful in order to minimise uncertainties in their quantification and describe better the relative importance of human mercury contributions. In particular, information is needed on the location of main natural emission areas and quantification of seasonal and annual variations of the emissions in addition to the total amounts, as well as separation of area sources (e.g. from areas with mercury-mineral containing soils and bedrock) and point sources (e.g volcanoes and fumaroles). Mercury is also emitted from ocean surfaces and the natural component of these emissions cannot be distinguished from re-emissions of previously deposited mercury. In this case, the total emissions to the atmosphere should be determined. In all cases, determination of speciation of mercury emitted from natural sources is of importance, including identification of elemental mercury, oxidised gaseous mercury and methylated mercury (i.e. mono- and dimethylmercury) (see for example submission from Canada, sub-42-gov).
- Further studies would be useful in order to improve the understanding of transport, transformation and fate of mercury in the atmosphere and in aquatic and terrestrial media, with particular focus on:

  1) Improvement of the quantitative understanding of the dynamics of mercury transformations and deposition processes in the atmosphere, including the Polar Mercury Depletion Events and oxidation/reduction processes in the free troposphere, laboratory and field investigations of oxidation/reduction processes, dry deposition and gas-liquid exchange processes;

  2) Determination of processes that control the mobilisation/immobilisation of mercury in soils and sediments, with main focus on leaching of mercury and methylmercury from forest soils to aquatic systems;

  3) Quantification of methylation/demethylation processes in aquatic ecosystems with specific focus on Arctic and coastal ecosystems and processes where oxidised mercury is reduced and released to the atmosphere and identification of the main pathways of methylmercury uptake in aquatic foodchains, with focus on Arctic and coastal ecosystems;

  4) Development and refinement of models describing chemical processes, dispersion and long-range transport of mercury, with special focus on hemispherical and global scale models, in order to facilitate quantitative descriptions of the global atmospheric cycling of mercury; and development of ecosystem models for mercury including mobility and bioaccumulation in terrestrial and aquatic ecosystems;

  5) Encouragement of technology transfer and international cooperation on standardising sampling and analytical methods for mercury species.
- Further studies of methylation, biomagnification and other processes and interactions in the food webs would be useful in order to describe better (e.g. in quantitative models) the links between human releases of mercury and observed concentration levels and impacts on humans, ecosystems and wildlife, (see for example submissions of Canada (sub-42-gov), COMERN (sub-5-ngo), Switzerland (sub-38-gov), Germany (sub-57-gov) and Thailand (sub-53-gov).
- Further studies of chemical reaction constants and other mechanisms affecting the transformation and fluxes of mercury in and between gaseous, liquid and solid phases in the atmosphere, as well as between the atmosphere and the aquatic and terrestrial environmental compartments, would help to

improve modelling of local, regional, hemispherical and global atmospheric transport of mercury, and better understand the global mercury cycle, (see for example submission of Italy/EU, sub-52-gov).

- Further measurements and assessments of re-emission of formerly deposited mercury from land and water surfaces might be needed to improve understanding of the global mercury cycle, including atmospheric long range transport and the relative importance of anthropogenic contributions, as well as enhancing possibilities for modelling and monitoring changes due to emissions reductions, (see for example submission of Italy/EU, sub-52-gov).
- Further studies of the evidence of the accumulated historical mercury contributions of humans to the environment, would be useful in order to describe better the relative importance of human impacts, (see for example submission of Canada, sub-42-gov).
- Further monitoring of the role of dry deposition of mercury would be useful in order to gain a better understanding of the relative contribution of wet versus dry deposition.

10.2.2 Examples of data gaps on human conduct in relation to mercury

- Further improvement and updating of assessments of global anthropogenic consumption, mobilisation, flows and releases of mercury (including atmospheric emission inventories, releases from waste treatment releases to aquatic environments etc.) would be useful in order to give a more complete picture of the situation and a better basis for selecting – on a global basis – which human sources should be addressed (and how), if reduction of human mercury releases are prioritised, (see for example section 6 and 7, submissions of the European Commission (sub-40-gov), Italy/EU (sub-52-gov), Switzerland (sub-38-gov), and comments from USA (comm-24-gov).
- Assessment of expected changes in global consumption and corresponding supply of mercury for different possible prevention/reduction scenarios would be useful in order to give a basis for decisions on management of supply (production, recycling and stocks management), in case this is prioritised, (see for example submission of the Nordic Council of Ministers, sub-84-gov).
- While it has been possible to assemble a reasonably complete picture of commodity stocks and flows among industrialised countries, the decreasing economic importance of mercury has been accompanied by a corresponding decline in public availability of production and use information. Moreover, an increasing share of mercury production and use occurs in developing countries, and as such, is little reported. Finally, many countries are unaware of flow analysis techniques. Specific data gaps, including those for mercury production and use, include:

  1) Annual basic production and use figures to allow for monitoring of programme success in reduction efforts, including such information as compiled by USA Geological Survey's annual "Mineral commodity surveys";

  2) A baseline economics study of primary virgin mining of mercury to provide insight into price-responsiveness of mines. Examples of information to be obtained include: legal status, ownership, relevant environmental regulation, per-unit cost of production, the nature and extent of public subsidies and annual production and sales since 1990;

  3) A periodic inventory of uses to guide future demand-reduction efforts, including an exhaustive list of specific uses (products and processes) and quantitative estimates of current use and characterisation of future demand for major end-use categories;

  4) A periodic inventory of non-market demand factors to support future demand projections, including a list of mandatory phase-outs/bans;

  5) A baseline survey of artisanal mining, including the quantity of gold mined, the number of miners and the quantity and rate of mercury used;

  6) Available techniques to perform materials flow analyses (MFA, SFA) in all industrial sectors need to be transferred and applied internationally.

- Improvement of emission inventories for anthropogenic emissions, including speciation of mercury, would be useful. Special attention should be paid to diffuse emissions from handling of elemental mercury (e.g. artisanal gold mining), household and uncontrolled waste incineration, as well as improvement of data from main point source categories (industries handling mercury, waste incinerators and power plants using fossil fuel).
- Further studies of mercury content in fossil fuels (coal, natural gas and petroleum) and the chemical and physical mechanisms and combustion conditions that influence mercury in a combustion system would be useful in order to obtain a better understanding of the contribution of fossil fuel combustion to the global mercury cycle and to determine effective approaches to reduce emissions from this source. In addition, it would be useful to imporive emission inventories for major anthropogenic sources with emphasis on feedstock (e.g. coal), process configuration (e.g. boiler design), emission control design and operation, and by-product use/disposal.
- Development and demonstration of integrated multi-pollutant (SO_2, NO_x, particulate material and mercury) control technology and continuous emission monitors would be useful.
- Development of information on good practices in prevention and control technology for cement production, conventional and artisanal mining, metallurgical industries and chlor-alkali plants would be useful for many countries.
- Further studies to develop commercially viable substitutes for those mercury product applications that still remain would be useful in order to reduce (and eliminate) intentional use of mercury in products and ultimately remove mercury from the waste stream.
- Development of a product substitution manual to be made available to many countries would be useful.
- Assessment of economic and social burdens and benefits of different possible prevention/reduction scenarios for mercury would be useful in order to give a better basis for selecting on a global basis which human sources should be addressed, if reduction of human mercury releases are prioritised.
- Further research on the interim and definitive storage of excess mercury and mercury-bearing waste would be useful in order to be able to permanently remove surplus quantities of mercury from society. Such storage solutions need to be monitored and retrievable, and should assure that the repository is maintained in a way that minimises emissions by all routes to the greatest extent possible. The transfer of mercury from society to such repositories must be conducted under occupationally safe conditions.

10.2.3 Examples of data gaps on adverse effects of current mercury levels

- Improvement of the understanding of dose-response relationships for methylmercury, elemental and inorganic mercury and their dependence on individual vulnerability, whether due to life-stage, nutrition, or other factors would be useful. In regard to methylmercury, information gaps include the possible impact on cardiovascular disease and mortality.
- Further research on the potential for health impacts of dental amalgam and vaccine additives containing mercury compounds would be useful.
- Coordinated and expanded monitoring of mercury concentrations in human hair and other relevant human samples would be useful in order to allow better definition of populations at risk from increased exposure. Such monitoring may also be used as a tool for prioritizing prevention actions on a local scale.
- Improvement of the understanding of the effects of co-exposure to different mercury species (and via different exposure routes) on dose-response relationships for humans would be useful.
- Further studies to improve the understanding of which – and how serious – ecotoxicological effects mercury currently has on different types of ecosystems and wildlife, in a global perspective, would be useful. For example, a growing body of evidence suggests that certain highly exposed wildlife

species are at risk from exposure to mercury through consumption of contaminated fish and shellfish. Key data gaps include an improved understanding of toxicological effects and ecological impacts of methylmercury on various species; interaction of mercury with other chemical and non-chemical stressors on ecological receptors; and ecological risk assessment methods.

- Development of practises for international coordination of monitoring of various environmental media would be useful.
- Assessment of environmental benefits and burdens of different possible prevention/reduction scenarios for mercury would be useful in order to give a better basis for selecting – on a global basis – which human sources should be addressed, if reductions of human mercury releases are prioritised (relates also to the issue of human conduct in relation to mercury).

10.2.4 Future use of information collected for the Global Mercury Assessment

1004. As mentioned several times in this report, a vast material has been submitted for use in this process and a network of contacts at national, regional and international levels have been established. Besides the benefit already derived from this material, it might also form part of a basis for further elaboration on several of the issues mentioned above, as well as other issues relevant to the global environmental implications of mercury, if such work would be deemed beneficial.

10.3 Development of Policy Tools

1005. On the basis of the summary provided in previous sections of this report on the complexity of chemical and physical mechanisms involved in the mercury cycle, one may wish to ask several questions, including the following: (see also Pirrone 2001; Pirrone *et al.* 2002) What are the qualitative and quantitative relationships between atmospheric input, deposition and mercury in aquatic environments? Is it possible to establish a deposition limit for mercury in order to regulate its emissions to the atmosphere? Do we know the relationship between the flux of mercury entering surface waters and the level of mercury (methylmercury) found in fish? Is it possible to evaluate the response time of the marine ecosystem in relation to changes in atmospheric emissions? Are any regional/hemispherical modelling frameworks validated and tested for assessing temporal and spatial patterns of mercury deposition to marine waters and its subsequent accumulation in the fish and ultimately its impact on the food chain?

1006. To help answer these questions and to assist the development and/or implementation of international strategies aiming to reduce the impact of mercury on human health and the environment, there is a need to develop policy tools that would help policy makers and different type of users and stakeholders to select the most cost-effective strategiesy.

1007. As an example, in Europe the Directorate General (DG) for Research of the European Commission is supporting mercury research programmes (i.e., MERCYMS) aimed to develop integrated modelling tools based on the concept of the Drive-Pressure-State-Impact-Response (DPSIR) framework, which has been used already as basis for the European Air Quality Directive on Ozone. Similar exercises aimed to develop integrated modelling tools are underway also elsewhere (i.e. USA, Canada).

1008. Figure 10.1 provides a conceptual DPSIR for mercury pollution reduction and control, as described by DG Research, where it is shown how our understanding of pressure factors interact with other areas of environmental knowledge such as impact assessment and monitoring (State), economic activity (Driver) and effective environmental policy (Response). A better assessment of a *spatial resolved emission inventories* play an important role in assessing the effects of anthropogenic activities on terrestrial and aquatic environments. The principal human demands for i.e. energy, transportation and food may be regarded as the "Drivers" for the production of mercury emissions to the ambient air. In order for an economy to continue to develop in a sustainable way, these sources of pollution must be managed. To do this we need to understand the "Impacts"- *i.e. what types of pollution affect which parts of the environment or human health*, and to what extent they do so. To decide whether action is necessary it is also helpful to know the "State" of the environment *i.e. evaluate whether the levels in the envi-*

ronment exceed those which will cause environmental harm. In taking appropriate action we must be able to respond in a focused way to prevent, control and reduce pollution while avoiding larger-scale damage to economic development. Emission inventories provide policy makers and the public with an understanding of the key polluting sources or the "Pressures", how these sources have developed with economic growth and how they are likely to contribute to pollution in the future. This understanding is essential for a focused "Response" to the problems associated with mercury pollution and to meet the demands of sustainable development. The Policy Response may refer to socio-economic scenarios with different Targets of mercury pollution control (i.e. BAU: Business as usual scenario; POT: Policy target scenario; DG: Deep green scenario,).

1009. Like mentioned in section 10.2 above, initiation of policy actions does not always require a full, detailed understanding of all elements of the conceptual framework.

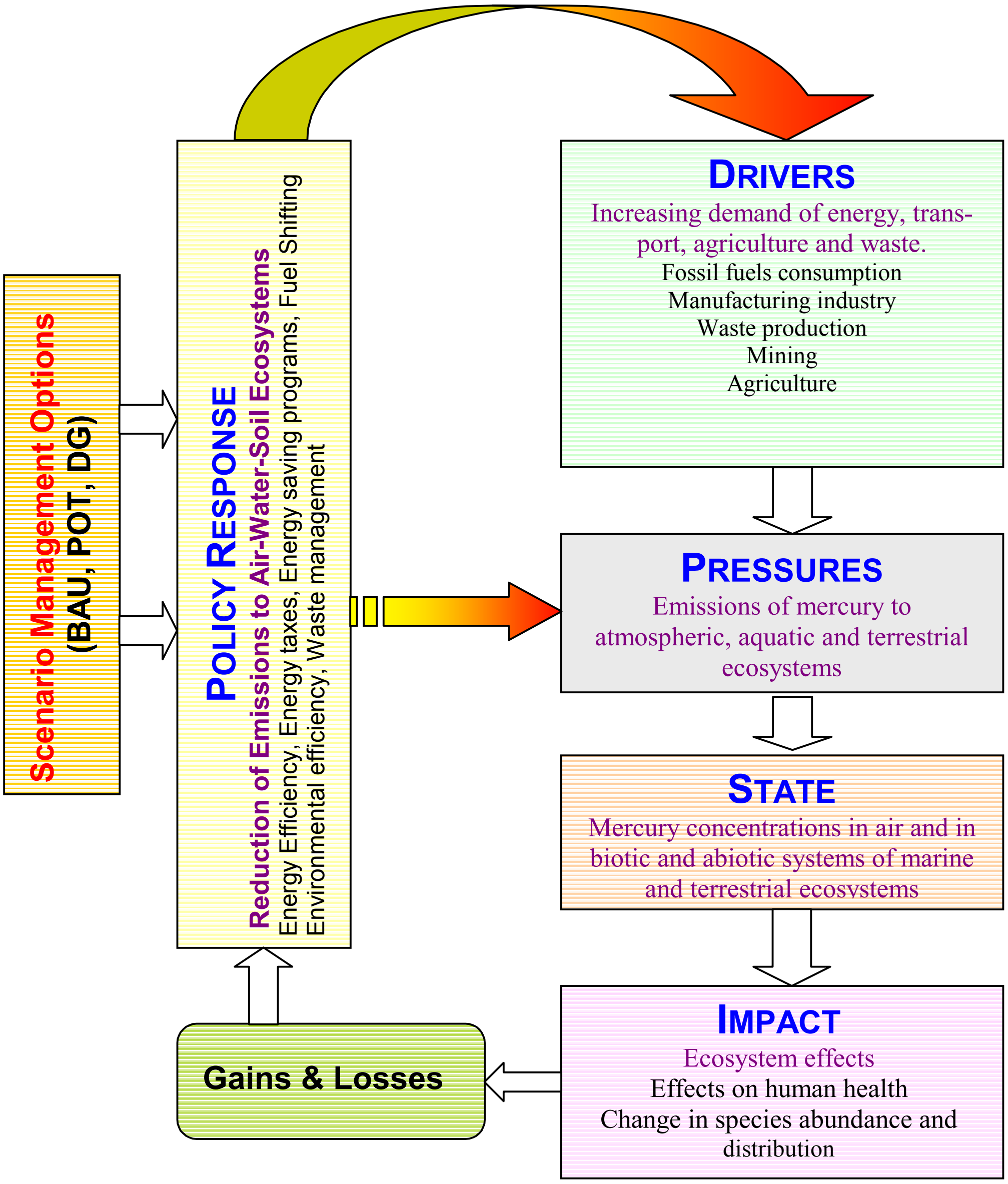

Figure 10.1 Example of a conceptual Driver-Pressure-State-Impact-Response (DPSIR) framework aimed to control and reduce the risk for human health and the environment due to mercury exposure BAU: Business as usual scenario; POT: Policy target scenario; DG: Deep green scenario. Source: MERCYMS Project funded by the European Commission – DG Research. Details can be found at http://www.iia-cnr.unical.it/MERCYMS/project.htm.

11 Options for addressing any significant global adverse impacts

11.1 Overview

1010. Chapter 11 responds to the request of the UNEP Governing Council to outline options for consideration by the Governing Council, addressing any significant global adverse impacts of mercury, inter alia, by reducing and or eliminating the use, emissions, discharges and losses of mercury and its compounds; improving international cooperation; and ways to enhance risk communication.

1011. As part of the implementation of Governing Council decision 21/5, UNEP established a Working Group to assist it in preparing for the Governing Council's discussions on the issue at its session in February 2003. The Global Mercury Assessment Working Group, at its first meeting held from 9 to 13 September 2002, finalized this assessment report for presentation to the Governing Council at its 22nd session. At this meeting, the Working Group arrived at a number of conclusions of relevance to the Governing Council's considerations:

- Based on the key finding of this report, the Working Group concluded that, in its view, there was sufficient evidence of significant global adverse impacts to warrant international action to reduce the risks to human health and/or the environment arising from the release of mercury into the environment. The reasoning behind its conclusion is described in section 11.2. While it was important to have a better understanding of the issue, the Working Group emphasized that it was not necessary to have full consensus or complete evidence in order to take action and therefore potentially significant global adverse impacts should also be addressed.

- The Working Group also agreed on an outline of options for recommendation on measures to address global adverse impacts of mercury at the global, regional, national and local levels. The options are outlines in section 11.3, while some additional aspects for consideration by the Governing Council are given in section 11.4. The options include measures such as reducing or eliminating the production, consumption and releases of mercury, substituting other products and processes, launching negotiations for a legally-binding treaty, establishing a non-binding global programme of action, and strengthening cooperation amongst governments on information-sharing, risk communication, assessment and related activities.

- Finally, the Working Group agreed to the need to submit to the Governing Council a range of possible immediate actions in light of their findings on the impacts of mercury, such as increasing protection of sensitive populations (through enhanced outreach to pregnant women and women planning to become pregnant), providing technical and financial support to developing countries and to countries with economies in transition, and supporting increased research, monitoring and data-collection on the health and environmental aspects of mercury and on environmentally friendly alternatives to mercury. These proposals for immediate action are given in section 11.5.

1012. By having initiated the development of this assessment report and the outline of options, the Governing Council will have a better basis for considering if any international action on mercury is called for in order to promote environmentally sound management of mercury and its compounds. The assessment report will contribute to increased awareness and understanding among decision makers of the major issues related to mercury and its compounds, thereby facilitating the debate on the issue at the next session of the Governing Council.

11.2 Conclusions with respect to significant global adverse impacts of mercury

1013. The Working Group confirmed the need for a global approach to address the issue of global adverse impacts of mercury, as there was evidence that mercury impacts on the environment have considerably increased globally due to human activities and that mercury was being transported globally to regions far from the source of release. The Working Group recommended that the Governing Council when considering any global adverse impacts of mercury at its next session, take into account the Working Group's conclusions with regard to significant global adverse impacts as set out below. (UNEP, 2002)

1014. For the reasons described below, the Working Group concluded that there was sufficient evidence of significant global adverse impacts to warrant international action to reduce the risks to human health and/or the environment arising from the release of mercury into the environment.

Hazardous properties of global relevance

1015. Mercury and its compounds are highly toxic substances. The potential toxicity of mercury for humans and other organisms varies widely depending on the chemical form, the pathway of exposure, the amount, and the vulnerability of the person exposed.

1016. An important factor about mercury is its ability to build up in organisms (bioaccumulate) and move up in the food chain (biomagnify). This is of particular relevance with respect to methylmercury, which accumulates to a greater extent than other forms of mercury and thus methylmercury is the primary species of concern.

1017. Once mobilized, mercury persists in the environment where it circulates in air, water, sediments, soil and biota in various inorganic and organic forms. It is capable of being transported over long distances, and releases on o continent can be deposited in other continents and elsewhere. Depending on local mercury pollution load, substantial additional contributions to the intake of total mercury can occur through air and water.

Human populations and ecosystems most as risk

1018. The general population is primarily exposed to methylmercury through diet and to elemental mercury through dental amalgam. Other routes of exposure include environmental releases and occupational activities. Exposure to mercury might also occur through the use of mercury-containing products, including vaccines containing mercury preservatives (Thimerosal/Thiomersal) and certain cosmetics.

1019. Some populations are especially vulnerable to mercury contamination. These include pregnant women, the newborn, children and indigenous people exposed to methylmercury through the consumption of contaminated fish, and communities dependant on foods that may contain high levels of methylmercury, such as fish and marine mammals.

1020. Workers who may be occupationally exposed to high levels of mercury are also at risk.

1021. There are also particularly vulnerable ecosystems and wildlife populations. These include top predators in aquatic and terrestrial food webs (e.g., fish-eating birds and mammals), Arctic ecosystems, wetlands, tropical ecosystems and soil communities.

1022. Mercury also gives rise to socio-economic effects on countries dependant on fisheries as an important activity, and may have impacts on agricultural production and land and aquatic uses.

Sources

1023. There is clear evidence that mercury impacts on the environment have considerably increased globally due to human activities. The most significant environmental releases of mercury are air emissions, but mercury is released in other ways, including discharges from various sources to water and land. The relative contributions to the releases of mercury from different source types vary between countries.

1024. Some examples of major sources of anthropogenic releases of mercury are:

(a) Releases from mobilization of mercury impurities:

- Coal-fired power and heat production (largest single source to atmospheric emissions)
- Energy production from other fossil carbon fuels
- Cement production (mercury in lime)
- Mining and other metallurgic activities involving the extraction and processing of virgin and recycling mineral materials, for example production of:
    - iron and steel
    - ferromanganese
    - zinc
    - other non-ferrous metals
- Petroleum production

(b) Releases from intentional extraction and use of mercury:

- Mercury mining
- Small-scale gold mining (amalgamation process)
- Chlor-alkali production
- Use of fluorescent lamps, instruments, dental amalgam fillings etc.
- Manufacturing of products containing mercury, for example:
    - thermometers
    - manometers and other instruments
    - electrical and electronic switches
- Biocides (e.g. seed-dressing, pesticides and slimicides)
- Use of other products, such as batteries, fireworks and laboratory chemicals

(c) Releases from waste treatment, cremation, etc. (originating from both impurities and intentional use of mercury):

- Waste incineration (municipal, medical and hazardous wastes)
- Landfills
- Cremation
- Cemeteries (release to soil)
- Recycling and storage

1025. Concern was expressed that highly contaminated industrial sites and mining operations continue to release mercury. It was also noted that land, water and resource management activities such as forestry and agricultural practices and flooding can make mercury more bioavailable. Methylation and bioaccumulation are also influenced by high levels of nutrients and organic matter in water bodies. Frequent extreme weather events can contribute to release of mercury through flooding and soil erosion. Concern was also raised regarding potential releases from surplus stocks of mercury and the need for proper storage.

1026. As uses are phased out in some parts of the world, mercury waste and recycling of mercury are on the increase. In this context, concerns have been identified regarding the export of mercury waste to other regions and the possible transfer of outdated technology to developing countries and countries with economies in transition.

Magnitude of the threat

1027. Mercury pollution has significant impacts at the local, national, regional and global levels. These impacts should be addressed through a range of actions at each of these levels, targeting both the supply of and demand for mercury.

1028. Mercury and its compounds have caused a variety of documented, significant global adverse impacts on human health and the environment throughout the world. Exposure studies from numerous geographic areas indicate that a significant portion of humans and wildlife throughout the world are exposed to methylmercury at levels of concern. Elevated methylmercury levels also have been measured in numerous freshwater and marine species throughout the world. Even areas with minimal local and national mercury releases, such as in the Arctic, are adversely affected due to the transcontinental and global transport of mercury.

1029. Some effects of mercury are linked to long-range transport while others are more local in character. Exposure through long-range environmental transport occurs where mercury released into air or water circulates and is transformed into methylmercury, which then comes into contact with humans and wildlife (e.g., through consumption of mercury-contaminated fish and mammals). By comparison, high exposures to inorganic mercury can occur through contact with mercury or mercury vapours at or near the source of use or release.

11.3 Conclusions with respect to possible options for addressing any significant global impacts of mercury

1030. The Working Group further recommended that the Governing Council should consider the outline of options for addressing those significant global adverse impacts of mercury as given in the text below. (UNEP, 2002)

1031. This outline lists possible options for recommendation on measures to address global adverse impacts of mercury at the global, regional, national and local levels. They can correspond to short, medium and long-term goals. Specific options may be adopted at different times in different countries or can be applied sequentially. In deciding which measures are most appropriate and effective at global, regional or national levels, varying socio-economic impacts should also be taken into account.

A. Measures to reduce and/or eliminate the use, emissions, discharges and losses of mercury and its compounds

1. Substituting products and processes

1032. Measures that involve substituting products and processes that contain or use mercury might include:

(a) Limiting or preventing use of mercury in products where alternatives exist and promoting development of appropriate alternatives for remaining essential uses;

(b) Limiting or preventing the intentional use of mercury except in artisanal mining activities until appropriate and affordable technology is transferred to the said sector;

(c) Limiting or preventing use of obsolete technology and requiring use of best available techniques and best environmental practices to reduce or prevent mercury releases into air and water;

(d) Gradual phasing-out of mercury already in use and mercury-containing products, after promoting the development of effective and affordable mercury substitutes and alternative technology.

2. Reducing mobilization of new mercury into the biosphere

1033. Measures to reduce production of raw materials and products that generate mercury releases might include:

(a) Reutilization of recovered or recycled mercury for essential use in a strictly controlled manner as opposed to mining and smelting of virgin mercury and careless use and discharge of mercury;

(b) Limiting or preventing the content of mercury present as impurities in fuels;

(c) Reducing and, where feasible, phasing out the mining of virgin mercury.

3. Reducing consumption

1034. Measures to reduce consumption of raw materials and products that generate mercury releases might include:

(a) Limiting or eliminating content of mercury present as such or as impurities in high volume materials, (for example, packaging);

(b) Limiting or preventing products containing mercury from being marketed nationally;

(c) Limiting or preventing products (for example batteries, pharmaceuticals, cosmetics etc) containing mercury from being exported and imported;

(d) Limiting or preventing the marketing of used or commodity-grade mercury;

(e) Establishing a “mercury bank” in order to keep account of the use of virgin mercury, recovered or recycled mercury in a strictly controlled system.

4. Controlling and monitoring emissions and releases

1035. Monitoring strategies should be defined with particular attention to the technical and economic capacities of countries. Each country may take measures to control mercury emissions and releases including through:

(a) Limiting or preventing mercury from processes from being released directly into the environment, air, water and soil through emission control techniques (for example, industrial point sources, including the chlor-alkali industry, oil and gas production, metallurgic industry etc., other sources such as municipal and medical waste incinerations, and activities such as small-scale mining);

(b) Limiting or preventing emissions of mercury from combustion of fossil fuels and processing of mineral materials by emission control technology, or by regulatory measures;

(c) Limiting or preventing the release of mercury from processes into the wastewater treatment system (in order to limit releases to the water recipient and to permit use of sludge);

(d) Controlling, confirming and improving the efficiency of measures for limiting or preventing mercury emissions and releases through end-of-pipe technology and to that end establishing emission standards and suitable cost-effective environmental monitoring.

5. Waste management

1036. Measures to reduce and/or eliminate mercury in wastes through mercury waste management might include:

(a) Limiting or preventing mercury in products and process waste from being released directly into the environment, by efficient waste collection;

(b) Limiting or preventing mercury in products and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment;

(c) Limiting or preventing mercury releases into the environment through treatment of household waste, hazardous waste and medical waste, by emission control technology;

(d) Limiting the mercury content in sewage sludge spread on agricultural land and limiting the use of solid incineration residues containing mercury in road-building, etc.;

(e) Limiting or preventing remarketing of wastes containing mercury;

(f) Retiring excess mercury through long-term waste management (terminal storage);

(g) Preventing mercury releases into the environment through the management of obsolete and waste pesticides and chemicals containing mercury;

(h) Promoting legal commitments among producers of mercury containing products to take responsibility for adequate waste treatment and final disposal of their products;

(i) Limiting or preventing the incineration of mercury containing products, materials and waste.

B. International cooperation

1037. International cooperation might be improved through:

(a) Promoting increased participation in existing regional and international conventions and agreements that deal with mercury and mercury compounds;

(b) Exchanging information regularly among international organizations, including the member organizations of the Inter-Organization Programme for the Sound Management of Chemicals, to ensure coordination of activities relevant to mercury and avoid duplication of efforts and waste of available resources;

(c) Supporting long-term monitoring and modelling initiatives at national, regional and international levels to ensure availability of comparable data and precise information that can guide policies and programmes aimed at reducing levels of mercury in the environment throughout the world;

(d) Exploring collaboration with regional and subregional centers, such as those of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, and supporting collaborative research programmes and initiatives to improve understanding of mercury sources, impacts on human health and the environment impacts on the fishing industry, fishing groups and people dependant upon fish for their livelihood and cycling in the environment;

(e) Supporting studies and clean-up programmes through international funding or financing initiatives for developing countries and countries with economies in transition;

(f) Filling information needs to assist developing countries and countries with economies in transition in targeting and prioritizing national or regional actions and strategies to reduce mercury use and releases (e.g. source and emissions inventory assistance), including through possible use of the Rotterdam Convention;

(g) Promoting surveys and information exchanges to identify international uses of mercury and to enhance our understanding of flows within and among countries from production through consumption and end-of-life storage or disposal;

(h) Establishing an international plan for the prevention of illegal import of mercury and mercury compounds as a raw material and/or as a hazardous waste.

C. Risk communication

1038. Risk communication relevant to the adverse effects of mercury and mercury compounds might be enhanced through:

(a) Raising awareness among policy and decision makers with regard to the adverse effects of mercury and mercury compounds;

(b) Promoting public information, awareness and education on the health and environmental effects of mercury and mercury compounds and the alternatives available to reduce exposure and reduce or eliminate releases and emissions of mercury especially to those vulnerable populations such as indigenous people, women and children, workers and communities living around industrial and mining activities etc.;

(c) Promoting curricula development in schools and training programmes of workers involved in mercury processing and handling;

(d) Establishing a clearing-house for information relevant to mercury, for example, information on risk management strategies, appropriate alternatives and related costs, and ensuring easy access to this information, especially for developing countries and countries with economies in transition;

(e) Establishing a network among Governments and other involved actors to exchange information on ongoing initiatives and efforts at national, regional and international levels to reduce or eliminate the adverse effects of mercury;

(f) Providing, for the general population, awareness of exposure risks to mercury through effective fish consumption advisories and other information dissemination methods. Enhancing, for vulnerable populations such as indigenous people, pregnant women and children, outreach and risk communication about mercury exposure;

(g) Promoting the awareness of the risks associated with the mobilization of mercury from geological sources and its accumulation in the biosphere;

(h) Promoting the awareness of the persistence of mercury and its ability to be transported, transformed and accumulated in food-chains.

D. Additional measures to support the reduction or elimination of uses, emissions, discharges and losses and limit the adverse impacts on human populations and the environment

1039. In addition to the measures listed in the previous section, which aim directly at reducing emissions and releases of mercury, a broader range of measures and management tools exist that supplement the regulatory infrastructure and support implementation of agreed reduction strategies and policies.

1. National, regional and international action

1040. The development of national, regional and international action plans to address the use and release of mercury might be promoted through:

(a) Developing inventories of uses, releases and possible global adverse impacts of mercury and mercury compounds as well as of existing sites polluted by mercury and mercury compounds to serve as a baseline for considering action on mercury globally, particularly in developing countries and countries with economies in transition;

(b) Developing and implementing an action plan setting out the policies necessary within each sector to reduce uses and releases of mercury through multi-disciplinary approaches and involving major stakeholders;

(c) Developing monitoring programmes including standardized measures linked to other international programmes through international networks, including training programmes and the exchange of expertise between on the one hand, developed and on the other, developing countries and countries with economies in transition;

(d) Promoting studies on socio-economic effects of different measures related to varying national conditions;

(e) Developing effective environmental policy tools based on integrated methodologies to assist in the management of mercury polluted sites resulting from anthropogenic activities;

(f) Exploring collaboration with the Basel Convention to develop guidelines for affordable waste management options for mercury wastes and research into methods for definitive storage and encourage and promote research into the search for viable alternative technologies and substitutes.

(g) Establishing a task force to coordinate and implement mercury action to resolve some of the uncertainties involving various issues.

2. Chemicals management

1041. The use of life-cycle assessment and chemicals management tools and techniques for addressing uses and releases of mercury might be promoted through:

(a) Setting environmental quality standards for maximum acceptable mercury concentrations in different media, such as air, water, soil and foodstuffs, in order to limit exposure of human populations and the environment (including occupational settings and vulnerable populations or ecosystems at special risk);

(b) Using Pollutant Release and Transfer Registers to track the environmental performance of industrial facilities using mercury or generating mercury waste and to stimulate voluntary initiatives by companies to reduce their releases and transfers of mercury;

(c) Using life-cycle assessment tools, facilitating the development and implementation of codes of conduct for various industrial sectors and producers, and promoting recognized environmental management systems, such as ISO 14.001, EMAS (the European Eco-Management and Audit Scheme), etc.;

(d) Developing best environmental practices or guidelines for best available techniques for various industrial sectors;

(e) Using economic incentives/disincentives to promote substitution of products, methods of analysis and processes that contain or use mercury or mercury compounds;

(f) Developing a framework to manage the transboundary movement of mercury, its compounds and products containing mercury and technology in particular into developing countries and countries with economies in transition. This may be achieved by adopting the process used by the Montreal Protocol, or through other models such as the Rotterdam Convention;

(g) Setting standards for maximum acceptable mercury emissions into the environment.

3. Voluntary measures

1042. Voluntary commitments and reduction programmes at national, regional and/or international levels to limit the use and release of mercury include:

(a) Promotion of voluntary commitments among producers of mercury containing products to take responsibility for ensuring appropriate handling and waste treatment of their products (for example, through information and training of users, product take-back schemes, etc.);

(b) Promotion of voluntary commitments among users of mercury containing products (for example, hospitals) to reduce or eliminate use and limit or avoid releases of mercury into the environment through appropriate handling and waste treatment;

(c) Promotion of voluntary reduction programmes within different private sector industries or activities to reduce and/or eliminate their uses and releases of mercury, thus stimulating the sector to identify and implement appropriate and effective solutions.

4. Technical and financial assistance

1043. Measures to provide technical and financial assistance to enhance the capacity of Governments, especially developing countries and countries with economies in transition, to monitor and assess emissions and releases of mercury and implement appropriate control measures include:

(a) Organizing training and capacity-building activities to support Governments in developing action plans and implementing the policies and strategies identified through the development of such plans;

(b) Establishing a mechanism for addressing the needs for capacity-building and technical and financial assistance of Governments, especially of developing countries and countries with economies in transition, taking into consideration the resources and assistance available from bilateral and multilateral assistance and partnerships through rigorous application of the principles and practice of needs assessment.

11.4 Additional aspects with respect to possible options for addressing any significant global impacts of mercury

1044. When considering the possible options that might be applied to address the adverse effects of mercury, the Working Group developed some additional aspects that should be taken into consideration, such as efficacy of national and regional measures versus international measures and binding versus voluntary measures. Some considerations relevant to these aspects are given below. (UNEP, 2002)

A. National and regional measures versus international measures

1045. Chapter 9 of this assessment report documents a considerable range of measures that have been implemented at the national and regional levels to deal with mercury and mercury compounds. Through such measures, a number of countries have achieved substantial reductions in emissions and releases of mercury from products and industrial processes. In addition, a number of coordinated regional approaches, both binding and non-binding, such as the Convention on Long-range Transboundary Air Pollution, the Convention for the Protection of the Marine Environment of the North-East Atlantic and the North American Regional Action Plan on Mercury, have supported national measures and contributed to additional reductions beyond national borders.

1046. Despite these successful national and regional initiatives, some countries consider that they might not be sufficient to ensure adequate protection of human health and the environment from the adverse effects of mercury, and are calling for the consideration of coordinated initiatives at the international level.

1047. If it is found that there are global problems related to mercury that should be addressed, it might be essential to the effectiveness of any reduction measures for the substantive commitments to be discussed and agreed at the international level. Any specific regional or national considerations may be addressed taking into account common but differentiated responsibilities within the commitments agreed to.

1048. Should countries within a region consider it necessary to set more stringent requirements than those in an international instrument, provisions for such regional agreements might be incorporated into an international initiative.

B. Non-binding versus binding measures

1049. As can be seen from chapter 9 of this assessment report, both voluntary non-binding and binding measures have been implemented successfully to address the negative effects of chemicals. Both approaches represent positive steps towards obtaining environmental aims and should be considered complementary rather than mutually exclusive.

1. Non-binding measures

1050. Examples of some non-binding measures specifically relevant to mercury are described in chapter 9 of this assessment report. Other measures relevant to chemicals management that have been successfully implemented at national, regional and international levels include:

(a) Codes of conduct, such as the UNEP Code of Ethics on the International Trade in Chemicals (1994) and the Food and Agriculture Organization of the United Nations (FAO) International Code of Conduct on the Distribution and Use of Pesticides (amended 1989);

(b) Voluntary reduction programmes with set reduction goals, for example, the United States of America Chlorine Institute's measures to reduce mercury use within United States mercury cell chlor-alkali facilities, the Euro Chlor voluntary commitments to OSPAR and the Great Lakes Binational Toxics Strategy;

(c) Ministerial/high-level declarations setting reduction goals, such as the North Sea Ministerial Declarations of the North Sea Conferences and the Nordic Environmental Action Programme of the Nordic Council of Ministers;

(d) Action programmes setting out detailed recommendations for responsible mercury management and control, such as the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities and the North American Regional Action Plan on Mercury.

1051. There might be some advantages to such non-binding measures. Binding instruments are often negotiated over a number of years, while non-binding instruments often may be adopted within a shorter time period. Because of their more flexible character, non-binding instruments can often be more ambitious in the goals they set. A non-binding instrument can incorporate measures to promote reporting, access to information, capacity-building and technical assistance. Although implementation is voluntary, States feel obliged to respect as far as possible the political commitments they have made. Non-binding instruments do not require a subsequent ratification or acceptance procedure and might contribute to a rapid implementation of commitments. Finally, participation in implementation might often be broader than for binding instruments that require ratification.

1052. As mentioned before, binding and non-binding measures are complementary rather than mutually exclusive. Non-binding commitments might also be used to ensure rapid implementation of environmental goals in expectation of the development and entry into force of binding measures. An example is the voluntary prior informed consent procedure of the UNEP London Guidelines for the Exchange of Information on Chemicals in International Trade (amended 1989) and the FAO Code of Conduct on the Distribution and Use of Pesticides (amended 1989), which was implemented on a voluntary basis from 1989 until the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade was adopted in 1998. This voluntary implementation is being continued during the interim period before the Convention enters into force, through the implementation of an interim prior informed consent procedure, based on the provisions of the Rotterdam Convention.

2. Binding instruments

1053. A binding instrument establishes firm legal commitments for those countries that ratify it and contains mechanisms to support implementation in accordance with the instrument's requirements. A binding instrument also requires the establishment of the administrative and technical procedures and structures required at national level.

1054. A binding instrument will often also have some benefits incorporated into it, such as the promotion of capacity-building and technical assistance as well as access to information and advice on substitutes and appropriate technology that might promote broad participation. Furthermore, a binding instrument can include elements, which are more or less voluntary such as recommended measures and commitments to long-term goals.

1055. When considering the advantages of a binding instrument, two options might be envisaged: developing a new instrument, or using an existing international instrument to address the adverse effects of mercury and mercury compounds. Some considerations relevant to these two options are given below.

(a) Option 1: Developing a new, binding instrument to address mercury

1056. Negotiating a separate, new international instrument on mercury might allow for the detailed regulation of all aspects Governments would find necessary to address, but would also require the establishment of the necessary infrastructure at the national and international levels to implement the provisions of the instrument. Negotiating an international, legally binding instrument often requires a number of years and substantial funding before the instrument can be adopted. Of the two most recently adopted international instruments regulating chemicals, the Rotterdam Convention took 30 months to negotiate and adopt (March 1996 to September 1998), while the Stockholm Convention on Persistent Organic Pollutants took 35 months (June 1998 to May 2001). Both conventions require 50 ratifications to enter into force, and neither has yet done so. In its deliberations, the Governing Council may also wish to give special priority to actions which the Working Group considers should be taken immediately and which appear in annex I, part C to the present report.

(b) Option 2: Using an existing international binding instrument to address mercury

1057. Using an existing international instrument to address the adverse effects of mercury might present two possibilities: incorporating mercury and mercury compounds, in accordance with existing provisions, into an existing instrument, or developing a protocol covering mercury and mercury compounds under an existing instrument.

1058. Relevant conventions, such as the Rotterdam Convention and the Basel Convention, aim at regulating transboundary trade in unwanted chemicals and hazardous wastes. The most recent international convention adopted and aimed at reducing releases from anthropogenic sources and minimizing or ultimately eliminating the use and production of certain chemicals is the Stockholm Convention. In addition, there are a number of binding instruments limited to a specific geographic area that address mercury, such as the Convention on Long-range Transboundary Air Pollution, the Convention for the Protection of the Marine Environment of the North East Atlantic and the Convention for the Protection of the Marine Environment of the Baltic Sea. Descriptions of all the above-mentioned instruments can be found in chapter 9 of this report.

1059. If considering this option, thought should be given as to whether the overall objectives of the specific existing convention and the control measures stipulated therein are appropriate to address the concrete issues identified with regard to mercury.

11.5 Proposals for immediate action to be considered by the UNEP Governing Council

1060. The Working Group also identified some special priority actions that it suggested the Governing Council might want to consider implementing immediately. These are described below. (UNEP, 2002)

1061. The Governing Council should consider inviting multilateral financing agencies, Governments and other partners to mobilize technical and financial resources to support national and regional efforts and capacity-building in areas such as the following:

(a) Begin the process to establish national implementation plans to examine:

- (i) Public awareness of the adverse effects of mercury and its compounds on health and the environment through training and workshops;
- (ii) An inventory of uses and release of mercury and mercury compounds as well as existing polluted sites to serve as baseline information;
- (iii) Establishment, where necessary, of legislation and regulations for enforcement;
- (iv) Regional information exchange;

(b) Build capacity through;

- (i) Training and workshops for a wide range of topics, including pollution prevention actions or key mercury use sectors (e.g., chlor-alkali facilities);
- (ii) Technical assistance in the development of facilities for analysis and monitoring;
- (iii) Provision of facilities for proper disposal of waste containing mercury including obsolete pesticides containing mercury;

(c) Promote awareness of alternative livelihood options and promote transfer of appropriate technology for the small-scale artisanal mining sector;

(d) Initiate one or more pilot projects in developing countries and countries with economies in transition to look at issues (a) to (c) mentioned above;

(e) Support research in order to better understand routes and nature of exposure and mercury cycling (transport and transformations, in particular the formation of methylmercury) in various environmental conditions in particular tropical and dry regions, for which limited information is available in developing countries and countries with economies in transition, and promote research on mercury (differentiation of natural and anthropogenic mercury in the air, in water and in soil, and in Arctic regions) in developed countries;

(f) Support research on the development of standardized analytical procedures and methods to support meaningful and cost-effective monitoring and modeling programmes (trends, health-related, hot spot monitoring and biomonitoring) as an essential component of mercury control measures;

(g) Assist countries in building broad based public awareness through incorporation of the subject “environmental education” in school curriculum;

(h) Establish a data bank regarding uses, sources, chemistry, import, export, health hazards, and research conducted in various areas of the world of mercury and its compounds. This data bank should be accessible to everyone;

(i) Undertake immediate research into best available environmentally friendly alternatives;

(j) Develop strategies for enhanced outreach and risk communication to reach sensitive populations (example pregnant women);

(k) Promote information exchange and collaboration, including scientific and technical information exchange on various topics such as long-range transport, monitoring and modelling, health and ecological risks, source characterization, source control technology, alternatives, pollution prevention techniques, nutrition and genetic factors among Governments in partnership with other public and private organizations;

1062. In so doing established organizations and existing international frameworks and infrastructure should be relied upon to the extent possible.

12 Glossary, acronyms and abbreviations

1063. The terms, acronyms and abbreviations below may appear in this document. In addition, a number of medical terms are explained in Chapter 3.

< - less than;

> - greater than;

°C - degree Celsius (centigrade);

µg – microgram (10^{-6} gram);

µg/kg body weight per day – micrograms per kilogram body weight per day; units used for describing intakes (or doses) of mercury such as intakes that are considered safe for humans (for example the US reference dose, described in section 4.2). In some cases the time unit weeks is also used.

ADI - acceptable daily intake;

AMAP - The Arctic Monitoring and Assessment Programme;

ATSDR – USA Agency for Toxic Substances and Disease Registry;

Balance (=budget) - totality of quantitative estimates of input and output substance fluxes for a given geophysical reservoir or societal entity;

bw - body weight;

Dry deposition - process of species transport from the atmosphere to the underlying surface at their direct (without precipitation) physical-chemical interaction with elements of the underlying surface; dry deposition is of a continuous character independent of the occurrence or absence of atmospheric precipitation;

EC – European Community (15 Member States - Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom);

EMEP – Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (under the LRTAP Convention);

ESP – Electrostatic precipitator; equipment used to reduce emissions of certain pollutants from combustion flue gases;

EU – European Union;

FAO – Food and Agriculture Organization;

FB – Fluidized bed; utility boiler combustion technology

FF - Fabric filter; filter type used to capture particulate matter (here: from combustion flue gases);

FGD – Flue gas desulfurization; process of/equipment for primarily minimizing emissions of sulfur from combustion flue gases;

GEF - Global Environment Facility;

Hg – mercury;

Hg^0 or Hg(0) - elemental mercury;

Hg^{2+} or Hg(II) - divalent mercury - the dominating mercury form in organic and inorganic mercury compounds. In the atmosphere, mercury species with divalent mercury are more easily washed out of the air with precipitation and deposited than elemental mercury;

Hg_p - particulate mercury - mercury bound in, or adsorbed on, particulate material. In the atmosphere, particulate mercury is deposited much faster than elemental mercury;

IARC - International Agency for Research on Cancer;

ILO - International Labor Organization;

IPCS – International Programme on Chemical Safety;

kg – kilogram;

l or L – litre;

LC_{50} - Lethal concentration, 50%; concentration of toxic substance in a medium (for example water) at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example fish;

LD_{50} - Lethal dose, 50%; dose (intake) of a toxic substance at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example in laboratory tests on mice, birds or other animals;

Life-time - In atmospheric physio-chemistry: Time during which the first order processes (or totality of the first order processes) of scavenging results in mercury species mass reduction in **e** times in a geophysical reservoir; for a reservoir with homogeneous mercury species distribution the life-time is equal to the ratio of the mass contained in the reservoir to scavenging rate. Since the mass of mercury in the reservior left to be reacted or removed decreases over time, the amount reacted or removed per unit of time decreases in a natural logarithmic fashion. For example, a lifetime of mercury of one year, does not mean that it would all be gone in one year if emissions were zero. It means that the rate of removal at the start of the time period in terms of mass per unit time would remove it all in one year, but since the rate of removal decreases as the mass of mercury left decreased, the amount of mercury left after one year would be (1/e) times the initial mass, where "e" is 2.71828183 defined to 8 decimals.
In descriptions of life-cycles of products: The time span from when the product is put into use (usually time of purchase) until it is no longer used or discarded;

LNB – Low-NO_x burner; utility boiler combustion technology designed specifically to generate relatively low levels of nitrogen oxides;

Load - the intensity of input of pollutants to a given ecosystem from the environment; atmospheric load - the intensity of input from the atmosphere;

LOEL - Lowest observed effect level (also called **LOAEL** – lowest observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

LRTAP Convention – Convention on Long-Range Transboundary Air Pollution;

m – meter;

MBL – marine boundary layer; the air right over the ocean surface, where exchange of mercury between the two compartments takes place;

MethylHg or **MeHg** – methylmercury;

metric ton – 1000 kg;

mg – milligram (10^{-3} gram);

MRL – minimum risk level; term used in evaluation of risk of toxic effects from various chemicals (such as methylmercury) on humans; the MRL is defined by US ATSDR as an estimate of the level of human exposure to a chemical that does not entail appreciable risk of adverse non-cancer health effects (see section 4.2);

MSC-E – Meteorological Synthesizing Centre – East (associated with the LRTAP Convention);

MSW – municipal solid waste;

MW – Megawatt;

MWC – municipal waste combustor;

MWh – Megawatt-hour;

Natural emission - mercury input to the atmosphere, which is not connected with current or previous human activity;

NEMA – National Electrical Manufacturers Association (in the USA)

ng – nanogram (10^{-9} gram);

NGO - non-governmental organization;

NOEL - No observed effect level (also called NOAEL – no observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

NRC – National Research Council of the United States of America;

OECD - Organization for Economic Cooperation and Development;

pg – picogram (10^{-12} gram);

POPs - Persistent Organic Pollutants;

ppb – parts per billion;

ppm - parts per million;

Pre-industrial state - a conventional term implying the state of the natural mercury cycle before the beginning of human industrial activity; in Europe the beginning of a noticeable production and consumption of mercury is related to medieval centuries;

PS - Particle scrubber; equipment designed to reduce emissions of particles from combustion flue gases

Re-emission - secondary input of mercury to the atmosphere from geochemical reservoirs (soil, sea water, fresh water bodies) where mercury has been accumulating as a result of previous and current human activity;

RfD – reference dose; term used in evaluation of risk of toxic effects various chemicals (such as methylmercury) on humans; the RfD is defined by US EPA 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 - see description in section 4.2;

SCR - Selective catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

SDA - Spray dryer adsorber system; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

Slag - waste material produced when coal is dug from the earth, or a substance produced by mixing chemicals with metal that has been heated until it is liquid in order to remove unwanted substances from it.

SNCR - Selective non-catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

TLV - threshold limit value;

TWA - time weighted average;

UN - United Nations;

UNCED - United Nations Conference on Environment and Development;

UNEP - United Nations Environment Programme;

US EPA – Environmental Protection Agency of the United States of America;

USA – United States of America;

Wet deposition - flux of substance from the atmosphere onto the underlying surface with atmospheric precipitation;

WHO - World Health Organization;

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