GENERAL DISTRIBUTION

OCDE/GD(94)98

OECD ENVIRONMENT MONOGRAPH SERIES NO. 103

RISK REDUCTION MONOGRAPH NO. 4:

MERCURY

Background and National Experience with Reducing Risk

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris 1995

OECD Environment Monograph Series No. 103

RISK REDUCTION MONOGRAPH NO. 4:

MERCURY

Background and National Experience with Reducing Risk

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris

Also published in this series:

Risk Reduction Monograph No. 1: Lead

Risk Reduction Monograph No. 2: Methylene Chloride

Risk Reduction Monograph No. 3: Selected Brominated Flame Retardants

Risk Reduction Monograph No. 5: Cadmium

RISK REDUCTION MONOGRAPHS

Risk Reduction Monograph No. 4: Mercury – Background and National Experience with Reducing Risk is the fourth in a series of OECD documents concerned with risk reduction activities for specific chemicals or groups of chemicals. The Risk Reduction Monographs contain sections on: the commercial life cycle; the environmental life cycle, including sources of environmental releases, pathways, and estimations of exposure; risk reduction and control measures; and international and national positions on the perceived risk.

Risk Reduction Monographs are part of the Environment Monograph series, which makes selected technical reports prepared by the OECD Environment Directorate available to a wide readership. Copies are available at no charge, in limited quantities, from the OECD Environment Directorate, Environmental Health and Safety Division, 2 rue André-Pascal, 75775 Paris Cedex 16, France.

Fax: (33-1) 45 24 16 75

TABLE OF CONTENTS

(continued next page)

FIGURES

Chapter 1:

Chapter 2:

TABLES

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 5:

FOREWORD

Background

In 1990, the Council of the OECD adopted a Decision-Recommendation on the Co-operative Investigation and Risk Reduction of Existing Chemicals [C(90) 163/Final]. This OECD Council Act is aimed at the reduction of risks from chemicals to the environment, and/or to the health of the general public or workers. It is based on the premise that international co-operation in risk reduction activities can enhance the technical and institutional aspects of risk management in Member countries through burden-sharing and a reduction of duplicative efforts. Furthermore, such activities can lead to a more effective use of the knowledge about risks that is being generated through, for example, national chemicals reviews and assessments; the OECD co-operative investigation of existing chemicals; and the work of other international organisations conducting hazard and risk evaluations, such as the United Nations' International Programme on Chemical Safety (IPCS).

International co-operation can provide a forum for the exchange of views on risk reduction strategies, thus increasing mutual understanding and facilitating the harmonization of programmes being undertaken at the national level. By means of this forum, technical barriers to trade can also be prevented.

The OECD's approach to risk reduction

The risk reduction process normally begins at the national level. However, the international character of the use and marketing of chemicals, and the mobility of certain chemicals in the environment, give risk reduction activities an international dimension.

The OECD's approach to risk reduction relies on the sharing and exchange of information on the management of specific chemicals. Readily available information concerning national risk reduction strategies can make comparative analyses possible. Where common interests emerge, the development and implementation of measured and consistent responses to unacceptable health and/or environmental risks can be facilitated.

In this context, risk reduction activities can take into account all stages of a chemical's commercial and environmental life cycles, beginning with the natural resources needed to produce it and extending through the chemical's uses to its eventual disposal. The chemical's health and environmental effects can be considered, together with exposure via all routes and media to different populations.

OECD work on mercury risk reduction

OECD Member countries chose mercury as one of the five chemicals (or groups of chemicals) to be included in the initial pilot project on co-operative risk reduction. An OECD Clearing House made up of lead countries for mercury began initial information collection in support of this Risk Reduction Monograph in 1992. Within the Clearing House, all drafts of the document including this final version were developed by Denmark and its consultant, Arne Jensen (Water Quality Institute), with technical support from the other Clearing House country, Sweden.

The Joint Meeting of the Chemicals Group and the Management Committee of the Special Programme on the Control of Chemicals recommended that this document be derestricted. It is being made public under the authority of the Secretary-General.

EXECUTIVE SUMMARY

The main purposes of this document are:

- to provide a summary of information regarding releases of mercury to the environment, the ensuing environmental and human exposures, and the way OECD Member countries perceive the risks associated with exposure to mercury; and

- to describe the actions Member countries and industry have taken, or contemplate taking, to reduce risks associated with exposure to mercury.

This document should be considered as 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. It may also suggest rationales and possibilities for concerted international actions.

Risk reduction activities for mercury are expected to continue to create information and technology conduits between Member countries, and to promote the development and transfer of knowledge regarding the nature and efficacy of responses to deal with unacceptable risks resulting from exposure to mercury.

Chapter Summaries

1. Mercury's Properties, Production and Uses

Mercury is a naturally occurring element in the earth's crust. Exploitation of the great majority of mercury deposits is by underground mining methods. The usual process of extracting mercury consists of heating the ore or concentrate in retorts or furnaces to liberate the mercury vapour, followed by condensation of the vapour.

Primary production of mercury worldwide decreased steadily from 10,000 tonnes in 1970 to 5500 tonnes in 1990. In 1991 the estimated primary production was less than 4000 tonnes. Secondary production accounts for a significant supplementary amount of mercury. The decrease in production has been matched by a decrease in the price of mercury.

The uses of mercury in the 1980s in OECD countries, in terms of average percentage of total use, were:

- batteries, 25 per cent;
- chlor-alkali industry, 28 per cent;
- electrical equipment and measurement equipment, 16 per cent;
- paint, 10 per cent;
- tooth fillings, 7 per cent;
- all other uses, such as thermometers and laboratory equipment, 14 per cent.

Mercury use in OECD countries has decreased over the last 15 years for most products. Significant reductions have been realised in its use in, for example, batteries, paints and seed dressing.

2. Environmental Releases

Environmental releases of mercury can be natural in origin (e.g. geological deposits, volcanic activities) or can occur from anthropogenic sources such as industrial activities, energy production, and the use and disposal of consumer products.

Environmental releases of mercury to air, water or land can be from soils and vegetation, forest fires, water surfaces, geological sources (such as crustal weathering, volcanic activities, earthquakes), and through crustal degassing, as well as from anthropogenic sources such as industrial activities, energy production, and the use and disposal of consumer products.

Various researchers have estimated the global annual natural emissions of mercury. Estimates vary over several orders of magnitude depending on the natural sources included in the estimate and the method of calculation. However, the concentrations of mercury in various compartments from natural and anthropogenic sources are highly variable. Therefore it would also be expected that emissions to air would be variable.

Global estimates of *anthropogenic* emissions in 1983 are:

- 3600 metric tonnes to air;
- 4600 metric tonnes to water, including atmospheric fall-out;
- 8300 metric tonnes to soil, including atmospheric fall-out.

However, more recent estimates indicate that anthropogenic emissions have decreased since these estimates were calculated, owing to changes in technology, reduced mercury use, and method of calculating emission factors.

Regional air emission estimates in the United States and the European Union show that the most important sources are coal combustion, followed by solid waste incineration. The greatest total releases to all media originate from industrial activity. Products containing mercury may result in releases to air, water or land after being landfilled or incinerated. The releases from landfills are difficult to quantify, however, because little is known about the processes which control the release of mercury.

Metal mining and production result in releases to soil, although in some countries such as Brazil serious widespread mercury pollution has been caused by the use of mercury in gold mining.

The most significant industrial process in terms of mercury emissions has been chlor-alkali production. However, today the greatest part of emissions is converted to a solid waste product which is disposed of in accordance with toxic waste regulations. The iron and steel industry and the fertilizer industry are mainly faced with the disposal of solid waste that contains mercury.

Other examples of releases are those from dental clinics and crematoria.

When industrial solid wastes and post-consumer products that contain mercury are not recycled or reused, they are generally disposed of in landfills or incinerators. For many years household batteries have been the largest source of mercury in discarded or used products. Municipal solid waste (MSW) incineration waste is estimated by US EPA to be 22 per cent of mercury releases to air in the United States, whereas an industry evaluation of existing municipal waste combustors arrived at a figure amounting to 14 per cent taking into account the type of control technology used at each facility. In the European Union, the air emission from MSW incineration is estimated to be 32 per cent, with only 8 per cent of the incinerators having gas-cleaning technology. When household waste is disposed of in landfills, it may give rise to the release of mercury to groundwater or to the atmosphere. The mercury concentration in household waste is expected to be reduced significantly in the next decade, following the expected decrease in the use of mercury in batteries.

3. Linkages to Exposure

Following its release to the environment, mercury is distributed and continuously redistributed between and within environmental compartments. It is more mobile than other heavy metals. In addition, inorganic mercury may be methylated by microbial activity to a more toxic organic form that is also transferable in the environment, giving rise to bioaccumulation and biomagnification in living organisms.

Anthropogenic mercury is released to the atmosphere as elemental mercury or as mercury compounds, in a gaseous form or as particulate material. Elemental mercury can be transported long distances, while mercury compounds are mostly deposited within 100 km of the source.

The greatest part of atmospheric mercury is generally assumed to be in the form of elemental mercury vapour. Mercury is removed from the atmosphere by dry and wet deposition.

Earlier deposited anthropogenic and/or natural mercury present in the environment can be volatilized again from the oceans (and lakes) as well as from soils. However, measurements are still too few to draw general conclusions about mercury fluxes in the environment on a regional (or larger) scale.

The major negative effect of environmental pollution by mercury is the biomagnification of methylmercury in the aquatic food chains. Methylmercury in biota has a biological half-life on the order of one year. Mercury in the aquatic environment is accumulated in biota in increasing concentrations with time, as well as at higher trophic levels.

These problems have led to a very large effort to try to determine the regulating mechanisms for the uptake of methylmercury in fish. However, there is still a need to elucidate conclusively the quantitative flux from different sources to fish.

Mercury concentrations in ocean surface waters are elevated in the northwest Atlantic compared with the northwest Pacific.

Recent studies have shown that mercury in forest soils, both natural and anthropogenic, can become mobile and be transported via run-off or flooding to surface waters. This can give rise to elevated mercury concentrations in the food chain, including in fish.

Studies, especially in Canada, have shown that land with presumably natural elevated mercury levels which is flooded by water produces high methylation rates of mercury, in turn giving rise to a high accumulation of mercury in fish.

Sediments in the aquatic compartment are a major sink for mercury. However, because several biogeochemical processes lead to element enrichment in surface sediments, mercury can be released to both water and the atmosphere.

There is a dynamic exchange of volatile mercury compounds between the atmosphere and the soil, mainly in the form of elemental mercury, which is easily absorbed by soil organic matter although it is available for re-emission from certain soils.

Because of the very high affinity of several mercury compounds to soil organic matter, leaching losses to subsoil horizons, groundwater or surface water are thought to be small for normal soils.

Several studies in Europe, the United States and Canada have suggested that mercury levels in the environment have been increasing. There is considerable debate among scientists about the significance of the contribution from natural versus anthropogenic sources.

The major human intake of mercury for the general population is from food and from dental amalgams. Fish and fish products are the dominant source of human exposure (and intake) because of their high retention of methylmercury. However, a significant intake of elemental mercury vapour with a high retention of mercury can occur from dental amalgams, dependant on the number of fillings. Exposure to inorganic mercury compounds is mainly from non-fish food with a low retention of mercury.

4. International and National Positions on the Risks from Mercury

This chapter contains assessments of the risks of mercury taken from International Programme on Chemical Safety (IPCS) Environmental Health Criteria documents.

Also presented in this chapter are Member country statements in regard to national positions on risks from mercury. These statements essentially present the rationale for any actions the country has taken or contemplates taking to address the effects associated with exposure to mercury. The risk assessments and risk characterisations that have led countries to take action have a national character. Countries develop positions on the need for risk reduction activities only after they have analysed the hazard and the significance of certain exposures and have factored in local social, economic and political considerations. These positions are usually arrived at after considerable debate on the numerous factors involved, and thus are not consistent across Member countries.

Some countries believe that the use of mercury and mercury-containing products should be reduced, with the goal of reducing the emission of mercury to the environment and the risks to human health. Other countries believe that the most significant routes of exposure to mercury should be managed to reduce risks to human health and the environment.

5. Mechanisms for Risk Reduction

Many Member countries have taken steps to reduce risks from mercury. Requests for information on mercury risk reduction activities were made to all Member countries in 1993-94. The national viewpoints presented in this chapter are mainly based on the responses to these requests.

Responses were received from the majority of Member countries. Generally, it can be concluded that:

- all countries have national legislation/regulations for mercury emissions to air, water and soil;
- mercury in seed dressing is forbidden for nearly all uses;
- the use of mercury in paint has been forbidden in most OECD countries;
- several countries have restricted or banned the use of mercury in thermometers;
- a few countries will prohibit the use of mercury in dental fillings towards the end of this century;
- today the general purpose battery can be produced without mercury;
- most countries have taken measures to reduce risks from occupational exposures;
- most countries have established guidelines or standards on the mercury content of fish or food;
- some countries have guidelines or standards for the mercury content in sewage sludge applied to agricultural land;
- some countries have established national or regional data bases (e.g. for sediments and fish) to identify areas of elevated metal levels;
- a few countries have a general ban on the use of mercury, with exemptions;
- several countries are parties to multilateral agreements to reduce the input of mercury to the marine environment.

Some national risk reduction measures are shown in the tables in Annex A to this chapter. Absence of information on a particular Member country does not mean that mercury risk reduction activities have not taken place in that country.

EXPOSE DE SYNTHESE

Le présent document a pour principaux objectifs :

- de résumer les informations relatives aux rejets de mercure dans l'environnement, à l'exposition qui s'ensuit pour l'environnement et l'être humain, ainsi qu'à la façon dont les pays Membres de l'OCDE perçoivent les risques associés à l'exposition au mercure ; et

- de décrire les dispositions que ces pays et les industries concernées ont prises ou envisagent de prendre afin de réduire les risques associés à l'exposition au mercure.

Ce document doit être considéré comme un «instantané» des réflexions les plus récentes relatives aux diverses activités liées à l'utilisation du mercure et à la pollution qui s'ensuit. Il peut aider à évaluer l'efficacité des stratégies nationales de réduction des risques liés au mercure en identifiant les tendances communes dans l'établissement de critères, de normes ou de politiques nationales. Il peut également aider à identifier des domaines où des actions internationales concertées se justifieraient et seraient possibles.

Les activités visant à réduire les risques associés au mercure devraient normalement continuer d'alimenter des flux d'informations et de technologie entre pays Membres et encourager l'acquisition et l'échange de connaissances relatives à la nature et à l'efficacité de mesures prises pour faire face à des risques inacceptables qui découlent de l'exposition au mercure.

Résumé des differents chapitres

1. Propriétés, production et utilisations du mercure

Le mercure est un élément présent à l'état naturel dans la croûte terrestre. L'exploitation de la grande majorité des gisements de mercure se fait par extraction minière souterraine. Le mercure est généralement obtenu par chauffage du minerai ou des concentrés de façon à libérer le métal sous forme de vapeur qui est ensuite condensée.

La production mondiale de mercure primaire a diminué régulièrement pour passer de 10 000 tonnes en 1970 à 5 500 tonnes en 1990. En 1991, on évaluait la production primaire à moins de 4 000 tonnes. La production secondaire représente une quantité supplémentaire de mercure non négligeable. Le recul de la production s'est accompagné d'une diminution du prix du mercure.

Dans les années 80, les utilisations du mercure dans les pays de l'OCDE se répartissaient de la façon suivante, en pourcentages moyens de l'utilisation totale :

- piles, 25 pour cent ;
- industrie du chlore et de la soude, 28 pour cent ;
- équipements électriques et appareils de mesure, 16 pour cent ;
- peintures, 10 pour cent ;
- amalgames dentaires, 7 pour cent ;
- tous autres usages, comme les thermomètres et les équipements de laboratoire, 14 pour cent.

L'utilisation de mercure dans les pays de l'OCDE a diminué au cours de ces quinze dernières années pour la plupart des produits. Les quantités de mercure utilisées, par exemple, dans les piles, les peintures et l'enrobage de semences se sont sensiblement réduites.

2. Rejets dans l'environnement

Les rejets de mercure dans l'environnement peuvent être d'origine naturelle (par exemple, dépôts géologiques, volcanisme) ou provenir de sources liées à l'activité humaine, comme l'industrie, la production d'énergie et l'utilisation et l'élimination de produits de consommation.

Le mercure rejeté dans l'environnement, que ce soit dans l'air, dans l'eau ou dans la terre, peut provenir des sols et de la végétation, des incendies de forêt, de la surface des eaux, de sources géologiques (telles qu'érosion de la croûte terrestre, volcanisme, tremblements de terre) et du dégazage de la croûte terrestre, aussi bien que d'activités humaines, comme l'industrie, la production d'énergie et l'utilisation et l'élimination de produits de consommation.

Divers chercheurs ont procédé à une estimation globale des quantités de mercure émises naturellement chaque année. Les évaluations diffèrent de plusieurs ordres de grandeur, suivant les sources naturelles considérées et les méthodes de calcul utilisées. Les concentrations de mercure dans divers milieux dues aux sources naturelles et anthropiques étant extrêmement variables, on peut s'attendre à des émissions atmosphériques également variables.

En 1983, les évaluations globales des émissions dues à l'activité humaine se répartissaient de la façon suivante :

- 3 600 tonnes dans l'air ;
- 4 600 tonnes dans l'eau, y compris les retombées atmosphériques ;
- 8 300 tonnes dans le sol, y compris les retombées atmosphériques.

Des évaluations plus récentes donnent une diminution des émissions dues à l'activité humaine par rapport aux estimations antérieures. La diminution est imputable à des progrès technologiques et à une moindre utilisation du mercure. Elle est également due à la méthode de calcul des facteurs d'émission.

Les évaluations des émissions atmosphériques aux Etats-Unis et dans l'Union européenne montrent que les sources les plus importantes sont d'abord la combustion de charbon puis l'incinération des déchets solides. Au total, les rejets les plus importants vers tous les milieux sont dûs à l'activité industrielle. Les produits qui contiennent du mercure peuvent entraîner, après épandage ou incinération, des rejets dans l'air, l'eau ou le sol. Ces émissions sont cependant difficiles à chiffrer, car on connaît mal les processus qui régissent la libération du mercure.

Les activités d'extraction et de production de métal s'accompagnent de rejets dans le sol, tandis que dans certains pays comme le Brésil, l'utilisation de mercure pour l'extraction de l'or a entraîné une pollution par le mercure à grande échelle.

Le procédé industriel le plus important en termes d'émissions de mercure est la production de chlore et de soude. Mais aujourd'hui, la plus grande partie des émissions est convertie en déchets solides qui sont éliminés conformément aux réglementations applicables aux déchets toxiques. La sidérurgie et le secteur des engrais sont surtout confrontés à l'élimination de déchets solides qui contiennent du mercure.

Il existe d'autres émissions comme, par exemple, celles qui proviennent des établissements dentaires et des crématoires.

Lorsque les déchets industriels solides et les déchets de produits de consommation contenant du mercure ne sont pas recyclés ou réutilisés, ils sont éliminés en général dans des décharges ou dans des incinérateurs. Pendant de nombreuses années, les piles à usage domestique ont constitué la source la plus importante de mercure dans les produits de rebut ou usagés. L'incinération des ordures ménagères aux Etats-Unis est évaluée par US EPA à 22 pour cent du rejet total vers l'atmosphère. Une évaluation faite par l'industrie qui tient compte de la technologie de contrôle en oeuvre dans chacun des incinérateurs municipaux étudiés arrive à 14 pour cent. Dans l'Union Européene les rejets dûs à l'incinération des ordures ménagères sont évalués à 32 pour cent du rejet total tandis que les incinérateurs équipés d'installations d'épuration des gaz contribueraient que 8 pour cent. Lorsque les ordures ménagères sont éliminées dans des décharges, elles peuvent donner lieu à des émissions de mercure vers les eaux souterraines ou vers l'atmosphère. La concentration de mercure dans les ordures ménagères devrait se réduire sensiblement dans les dix prochaines années à la suite de la diminution que devrait connaître l'utilisation du mercure dans les piles à usage domestique.

3. Relations avec l'exposition

Une fois libéré dans l'environnement, le mercure se répartit dans les divers milieux entre lesquels il est constamment remis en circulation. Il est plus mobile que les autres métaux lourds. En outre, le mercure inorganique peut être méthylé sous l'effet de l'activité microbienne et prendre une forme organique plus toxique qui est également transférable dans l'environnement, ce qui aboutit à une bio-accumulation et à une bio-amplification dans les organismes vivants.

Le mercure dû à l'activité humaine est libéré dans l'atmosphère sous forme de mercure élémentaire ou de composés mercuriels gazeux ou particulaires. Le mercure élémentaire peut être transporté sur de longues distances, tandis que les composés mercuriels se déposent pour la plupart à moins de 100 kilomètres de la source.

On estime, en général, que la plus grande partie du mercure présent dans l'atmosphère est sous forme de vapeur de mercure élémentaire. Celui-ci est éliminé de l'atmosphère sous forme de dépots secs et humides.

Le mercure déjà déposé et le mercure naturel présent dans l'environnement peuvent être à nouveau volatilisés à partir des océans (et des lacs) aussi bien qu'à partir des sols. Toutefois, trop peu de mesures ont été effectuées jusqu'à présent pour que l'on puisse établir des conclusions générales sur les flux de mercure dans l'environnement à une échelle régionale (ou plus large).

Le principal effet négatif de la pollution de l'environnement par le mercure est la bio-amplification du méthylmercure dans les chaînes alimentaires aquatiques. Le demi-temps de séjour du méthylmercure dans les organismes vivants est de l'ordre d'une année. En milieu aquatique, le mercure s'accumule dans les organismes vivants à des concentrations qui augmentent avec le temps, et gagne des niveaux trophiques plus élevés.

Ces problèmes ont été à l'origine d'un effort très important visant à élucider les mécanismes qui régulent l'absorption de méthylmercure chez le poisson. Il reste cependant beaucoup à faire avant d'établir définitivement les flux quantitatifs provenant de différentes sources et aboutissant aux poissons.

Les concentrations de mercure dans les eaux de surface de l'Atlantique Nord-ouest sont plus élevés que dans le Pacifique Nord-ouest.

Des études récentes ont montré que le mercure présent dans les sols forestiers peut devenir mobile et être entraîné par le ruissellement ou les inondations vers les eaux de surface. Ce phénomène peut conduire à des concentrations de mercure élevées dans la chaîne alimentaire, en particulier chez les poissons et cela même dans les lacs éloignés des sources d'émission.

Des études, réalisées notamment au Canada, ont montré que les terres dont les concentrations naturelles de mercure sont vraisemblablement fortes produisent, en cas d'inondation, des taux élevés de méthylation du mercure, entraînant par la suite une forte accumulation de mercure chez les poissons.

Les sédiments du milieu aquatique constituent un piège majeur pour le mercure. Cependant, du fait de la méthylation du mercure par des micro-organismes des sédiments, le mercure peut être à nouveau libéré, aussi bien vers l'eau que vers l'atmosphère.

On constate un échange dynamique de composés mercuriels volatils entre l'atmosphère et le sol, essentiellement sous forme de mercure élémentaire, qui est facilement absorbé par les matières organiques du sol, bien qu'il soit susceptible d'être libéré à nouveau à partir de certains sols.

Etant donné la très grande affinité de plusieurs composés mercuriels pour les matières organiques des sols, on estime que les pertes par lixiviation vers des horizons du sous-sol, vers les eaux souterraines ou vers les eaux de surface, devraient être faibles dans le cas des sols courants.

De plusieurs études faites en Europe, aux USA et au Canada, il ressort une augmentation des concentrations de mercure dans l'environnement. Les scientifiques débatent des parts respectives à attribuer aux émissions naturelles et anthropiques.

Pour l'ensemble de la population humaine, les principales voies d'absorption de mercure sont l'alimentation et les amalgames dentaires. Le poisson et les produits à base de poisson sont la principale source d'exposition de l'être humain (et d'absorption), en raison de la rétention élevée du méthylmercure. Cependant, une absorption non négligeable de vapeur de mercure élémentaire, accompagnée d'une rétention élevée, peut intervenir du fait des amalgames dentaires, en fonction du nombre de plombages. L'exposition à des composés inorganiques du mercure est essentiellement due aux denrées alimentaires, autres que du poisson, et contenant peu de mercure.

4. Positions adoptées au niveau international et national quant aux risques imputables au mercure.

Ce chapitre contient les évaluations des risques liés au mercure établies dans le cadre du Programme international sur la sécurité des substances chimiques (PISSC).

On trouvera également dans ce chapitre des déclarations provenant de pays Membres relatifs à l'attitude adoptée actuellement par les divers pays vis-à-vis des risques liés au mercure. Pour l'essentiel, ces déclarations donnent les raisons à la base de toute disposition prise par un pays donné pour faire face aux effets associés à l'exposition de l'environnement ou de l'être humain au mercure. Les évaluations et les descriptions nationales des risques qui ont conduit les pays à prendre des mesures ont un caractère profondément national. Les pays n'ont défini leur position sur la nécessité de lancer des activités de réduction des risques qu'après avoir analysé le danger que présentaient certaines expositions, ainsi que leur ampleur, et avoir pris en compte des considérations locales d'ordre social, économique et politique. Comme ces positions sont habituellement établies après un débat approfondi sur les nombreux facteurs impliqués, il ne faut par conséquent pas s'attendre à ce qu'elles soient homogènes entre les différents pays Membres.

Certaines pays ont la conviction qu'il faut limiter l'utilisation du mercure et des produits le contenant afin de réduire les émissions dans l'environnement et par la même les risques pour la santé humaine. D'autres pays pensent que, pour réduire les risques tant pour la santé humaine que pour l'environnement, il suffit de contrôler les voies d'exposition les plus importantes.

5. Dispositifs pour la réduction des risques

De nombreux pays Membres ont pris des mesures pour réduire les risques liés au mercure. Tous les pays Membres ont été invités en 1993-1994 à fournir des informations sur leurs activités visant à réduire de tels risques. Les points de vue nationaux présentés dans ce chapitre sont essentiellement fondés sur les réponses obtenues.

La majorité des pays Membres ont fourni des réponses. D’une façon générale, on peut en conclure que :

- tous les pays disposent d’une législation/réglementation nationale relative aux émissions de mercure dans l’air, l’eau et le sol ;
- le mercure est interdit dans les enrobages des semences pour pratiquement toutes les utilisations ;
- l’utilisation de mercure dans les peintures a été interdite dans la plupart des pays de l’OCDE ;
- plusieurs pays ont limité ou interdit l’utilisation de mercure dans les thermomètres ;
- quelques pays vont interdire l’utilisation du mercure dans les amalgames dentaires vers la fin de ce siècle ;
- à l’heure actuelle, on peut fabriquer des piles tous usages sans mercure ;
- presque tous les pays ont pris des mesures dans le but de diminuer les risques qu’encourent les travailleurs exposés ;
- presque tous les pays ont adopté des critères ou des normes pour le contenue en mercure du possion et des denrées alimentaires ;
- certaines pays ont adopté des critères ou des normes pour le taux de mercure dans les boues d’épuration appliquées sur les terres agricoles ;
- des pays ont developpé des bases de données nationales ou régionales (par example pour les sédiments et les poissons) afin d’identifier des zônes où les taux de métaux sont élevés ;
- quelques pays appliquent une interdiction générale à l’utilisation du mercure, avec diverses exceptions ;
- plusieurs pays participent à des accords multilatéraux visant à réduire les apports de mercure dans le milieu marin.

Quelques mesures nationales de réduction des risques sont récapitulées dans la série de tableaux annexée à ce chapitre. L’absence d’informations pour un pays Membre donné ne signifie pas que ce pays ne consacre pas d’activités à la réduction des risques liés au mercure.

CHAPTER 1

MERCURY’S PROPERTIES, PRODUCTION AND USES

1.1 Physical and chemical properties

The physical and chemical properties of mercury are summarized in IPCS Environmental Health Criteria document No. 86 as follows:[1]

Mercury can exist in a wide variety of physical and chemical states. The different chemical and physical forms of this element all have their intrinsic toxic properties and different applications in industry and agriculture, and require a separate assessment of risk.

Mercury, along with cadmium and zinc, falls into Group IIb of the Periodic Table. In addition to its elemental state, mercury exists in the mercury (I) and mercury (II) states in which the mercury atom has lost one and two electrons, respectively. The chemical compounds of mercury (II) are much more numerous than those of mercury (I).

In addition to simple salts, such as chloride, nitrate and sulphate, mercury (II) forms an important class of organometallic compounds. These are characterized by the attachment of mercury to either one or two carbon atoms to form compounds of the type RHgX and RHgR’ where R and R’ represent the organic moiety. The most numerous are those of the type RHgX. X may be one of a variety of anions. The carbon-mercury bond is chemically stable. It is not split in water nor by weak acids or bases. The stability is not due to the high strength of the carbon-mercury bond, but to the very low affinity of mercury for oxygen. The organic moiety, R, takes a variety of forms, some of the most common being the alkyl, the phenyl, and the methoxyethyl radicals. If the anion X is nitrate or sulphate, the compound tends to be "salt-like", having appreciable solubility in water; however, the chlorides are covalent, non-polar compounds that are more soluble in organic solvents than in water. From the toxicological standpoint, the most important of these organometallic compounds is the subclass of short-chain alkyl mercurials in which mercury is attached to the carbon atom of a methyl, ethyl, or propyl group.

1.2 Production

The major mercury deposits are commonly formed at comparatively shallow depths (a few metres to over 700 metres). Exploitation of the great majority of mercury deposits is by underground mining methods; the deposits are usually too small and irregular for open-pit mining to be economical. The milling of the ore consists in crushing, followed sometimes by

---

[1] IPCS (International Programme on Chemical Safety), *Environmental Health Criteria 86: Mercury – Environmental Aspects*, Geneva, 1989, page 12.

screening. Where the ore grade is less than about 2 g/kg, the ores may be beneficiated by flotation. Roasting of the ores is so efficient in extracting the mercury, however, that beneficiation is not widely used.

The usual mercury extraction process consists in heating the ore or concentrate in retorts or furnaces to liberate the mercury vapour, followed by condensation of the vapour (Nriagu 1979).

Mercury production has declined steadily in the last 20 years **(Figures 1.1 and 1.2)**. Worldwide primary production decreased from 10,000 metric tonnes in 1970 to 5500 metric tonnes in 1990. This figure was expected to be even lower in 1991.

There is significant secondary production of mercury. In 1982, the OECD (1985) estimated it to be as much as 40 per cent of primary production. Secondary production includes recycling, recovery, and industrial reprocessing of mercury. The extent of recent secondary production has not been possible to quantify; however, it should be noted that secondary production does not add new mercury into society, but rather adds to the flow of mercury. In the United States, secondary industrial production varied between 10 and 20 per cent of total mercury consumption in 1985-89 (Minerals Yearbook 1989).

Stockpiles of mercury in the United States are maintained for strategic defense purposes by the National Defense Stockpile (NDS) and the Department of Energy (DOE). NDS legislation enacted in 1992 authorizes the disposal of the entire amount of mercury stocks from the NDS. This mercury is to be reused over a period of years, in accordance with the legislative mandate that the sale be carried out in such a manner as to avoid undue disruption of the usual markets of mercury producers, processors and consumers. At the end of 1993, there was an estimated 4466 metric tonnes of mercury in the NDS groups (United States Department of Commerce 1993).

As can be seen in **Figure 1.3**, the decrease in production of mercury since the early 1970s has been accompanied by a price decrease (British Geological Survey 1990). Such a decrease will have an influence on the attractiveness of secondary production (i.e. recycling) of mercury.

Figure 1.1 Primary Production of Mercury, 1925-1987

(tonnes per year, from *Mineral Yearbook*, 1972-1989)

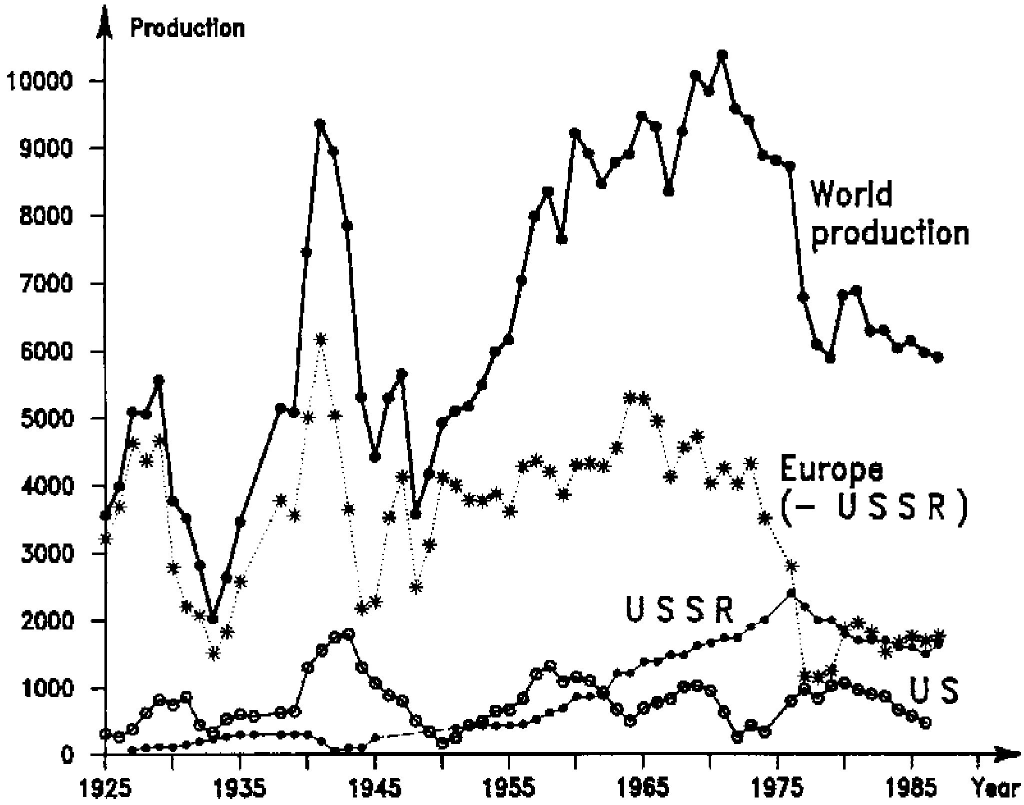


Figure 1.2 Production of Mercury from Ores and Concentrates

(metric tonnes, from *Metallgesellschaft 1992*, based on figures in Appendix 1)

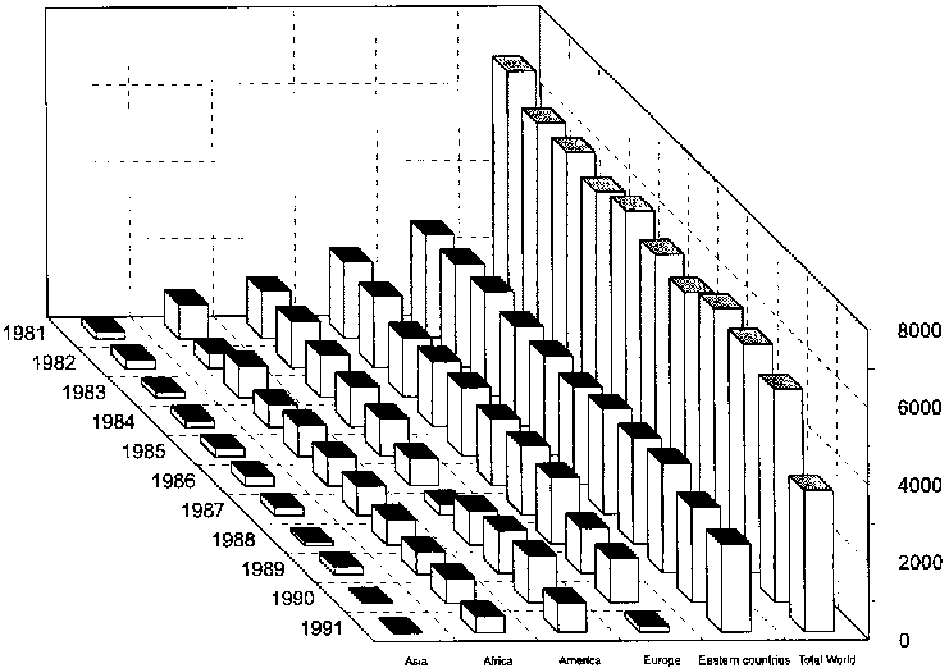
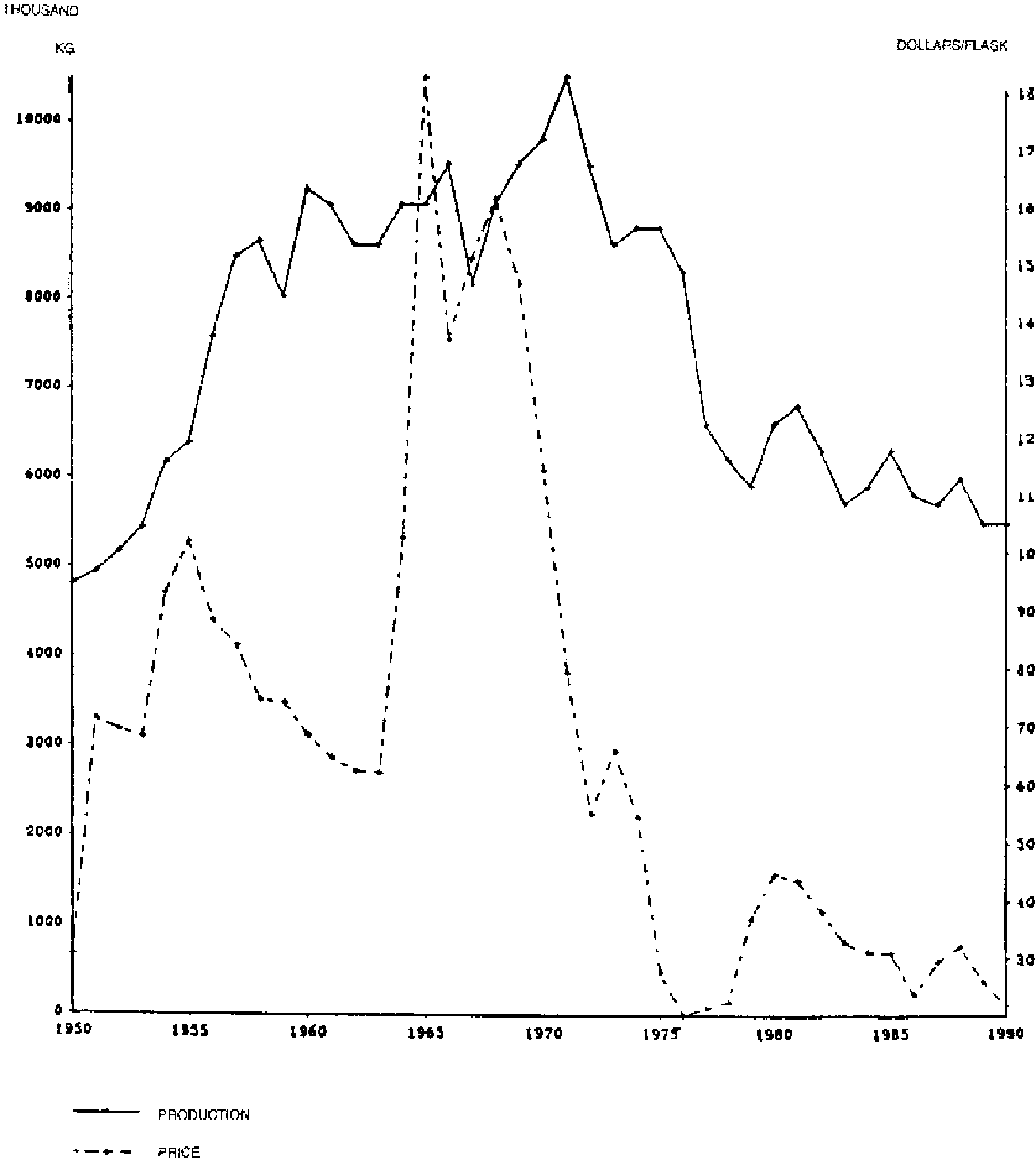


Figure 1.3 World Production of Mercury Compared with the Annual Average Price in the United States

(according to *Metals Week*, expressed in constant 1985 US dollars; from British Geological Survey, *World Mineral Statistics 1988 to 1989*)



1.3 Uses

The main uses of mercury vary among countries; however, based on the responses to an OECD questionnaire submitted to Member countries (Appendix 2) the general range of consumption patterns for 1988-92 can be stated as follows (Appendix 3):

- batteries, range 3 to 69 per cent (average 25 per cent);
- chlor-alkali industry, range 2 to 78 per cent (average 28 per cent);
- electrical equipment and measurement equipment, range 1 to 50 per cent (average 16 per cent);
- paint, range 0.1 to 16 per cent (average 10 per cent);
- tooth fillings, range 2 to 51 per cent (average 7 per cent);
- all other uses, such as thermometers, laboratory uses, and others, average 14 per cent.

Figure 1.4 shows the relative consumption of mercury-containing batteries, tooth fillings and chlor-alkali compared with other mercury-containing products *within* each country. For example, the consumption of mercury-containing batteries in the United Kingdom makes up 18 per cent of the total consumption of mercury-containing products in that country. **Figure 1.5** compares the *total* consumption of mercury-containing batteries, tooth fillings and chlor-alkali in tonnes across major regional areas. The figures are based on data in Appendix 2 and Appendix 3

In OECD countries (Appendix 2) the main uses of mercury-containing products have decreased over the last 15 years. In Denmark the use of mercury decreased from 30 tonnes per year in 1977-78 to 16 tonnes in 1982-83, and a further reduction to about 10 tonnes was estimated for 1990. In France, consumption decreased from 300 tonnes per year in 1970 to 100 tonnes in 1985-87 (Cossa et al. 1990), with a further reduction to 61.2 tonnes in 1990-92 (Appendix 2).

The figures from Norway demonstrate that mercury consumption was reduced from 8.7 tonnes in 1985 to less than 3.7 tonnes in 1988-90. In Switzerland the consumption of mercury decreased from 20 tonnes in 1986 to 10 tonnes in 1990. Similar reductions have taken place in the Netherlands, where consumption was halved between 1980 and 1989.

Currently, use in the chlor-alkali industry, in batteries, and in the electronics industry taken together account for most mercury consumption.

As the United States is one of the largest users of mercury-containing products, the shift in use patterns in that country is of particular significance. As can be seen in **Figure 1.6**, the use of mercury-containing products in 1990 was reduced by a factor of 3.6 from a high in 1968. One important reason for this decline is the fact that mercury was no longer used in agriculture, amalgamation, the pulp and paper industry, and the pharmaceutical industry. Electrical equipment, batteries and the chlor-alkali industry each still account for one third of consumption. Paint accounted for up to 18 per cent until 1990, when a drastic decrease took place due to new restrictions on mercury use in paints. Battery use shows a substantial downward trend from 1989 to 1990, whereas other uses show smaller changes since 1984 (Mineral Yearbook 1986, 1989, 1990; also see Appendix 4).

Figure 1.4 Relative Consumption of Mercury (1988-1992) in Different Countries

(per cent, based on figures in Appendix 3)

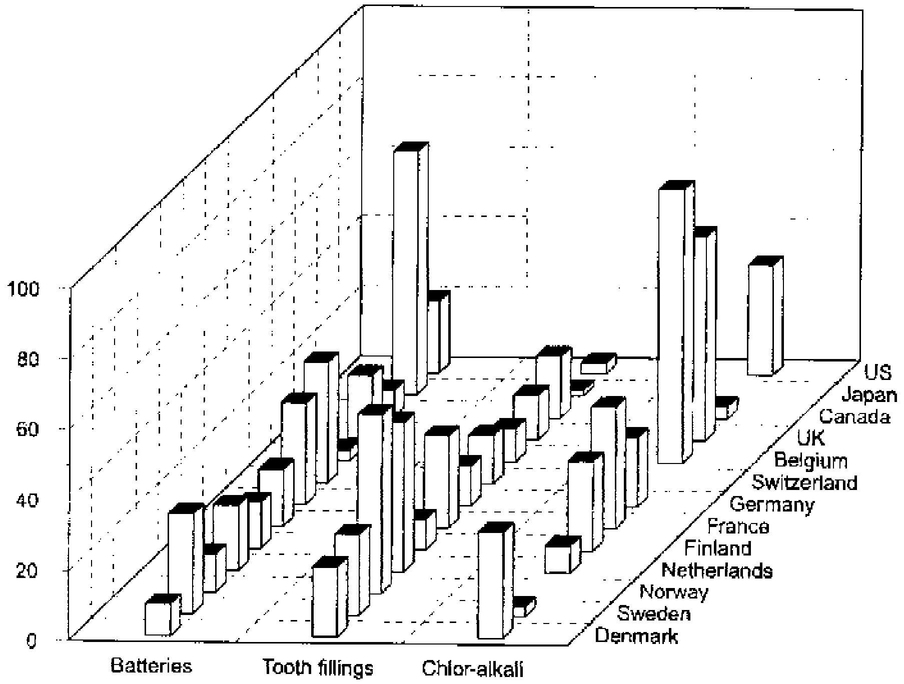


Figure 1.5 Use Categories of Mercury (1988-1992) in Batteries, Tooth Filling and Chlor-alkali Production

(metric tonnes per year, based on figures in Appendix 2)

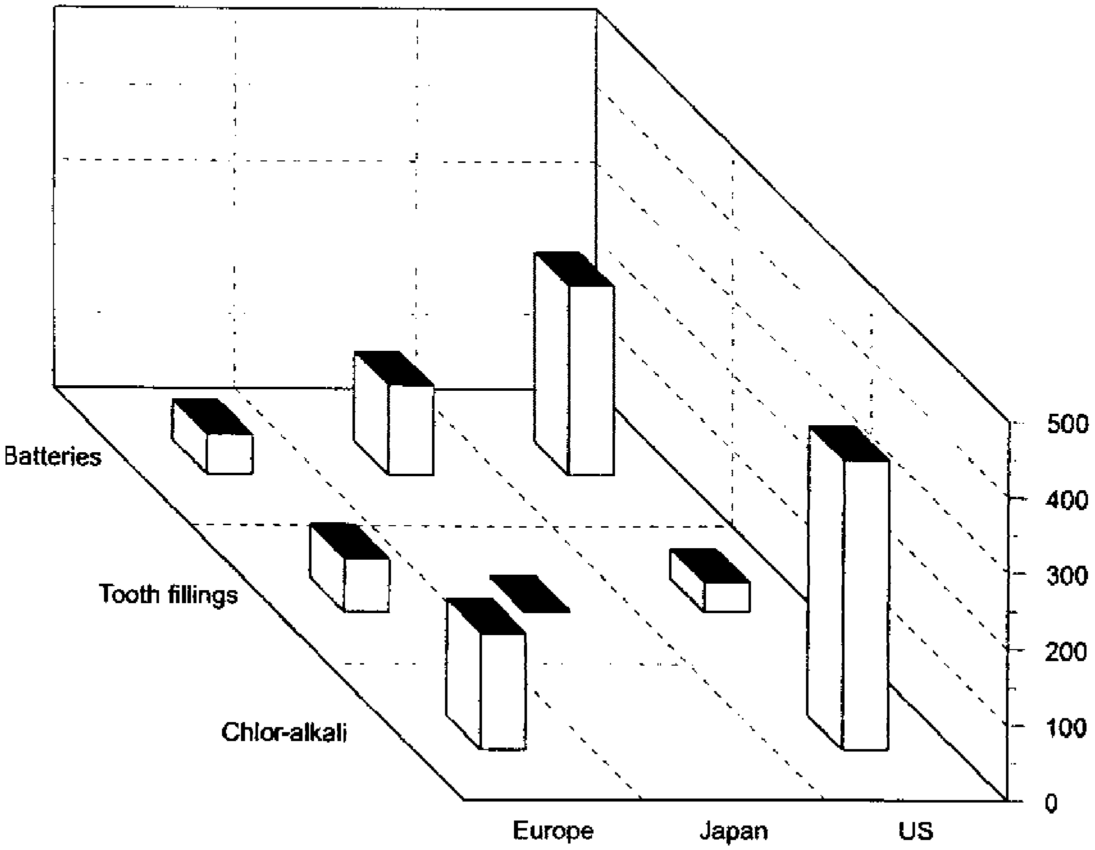
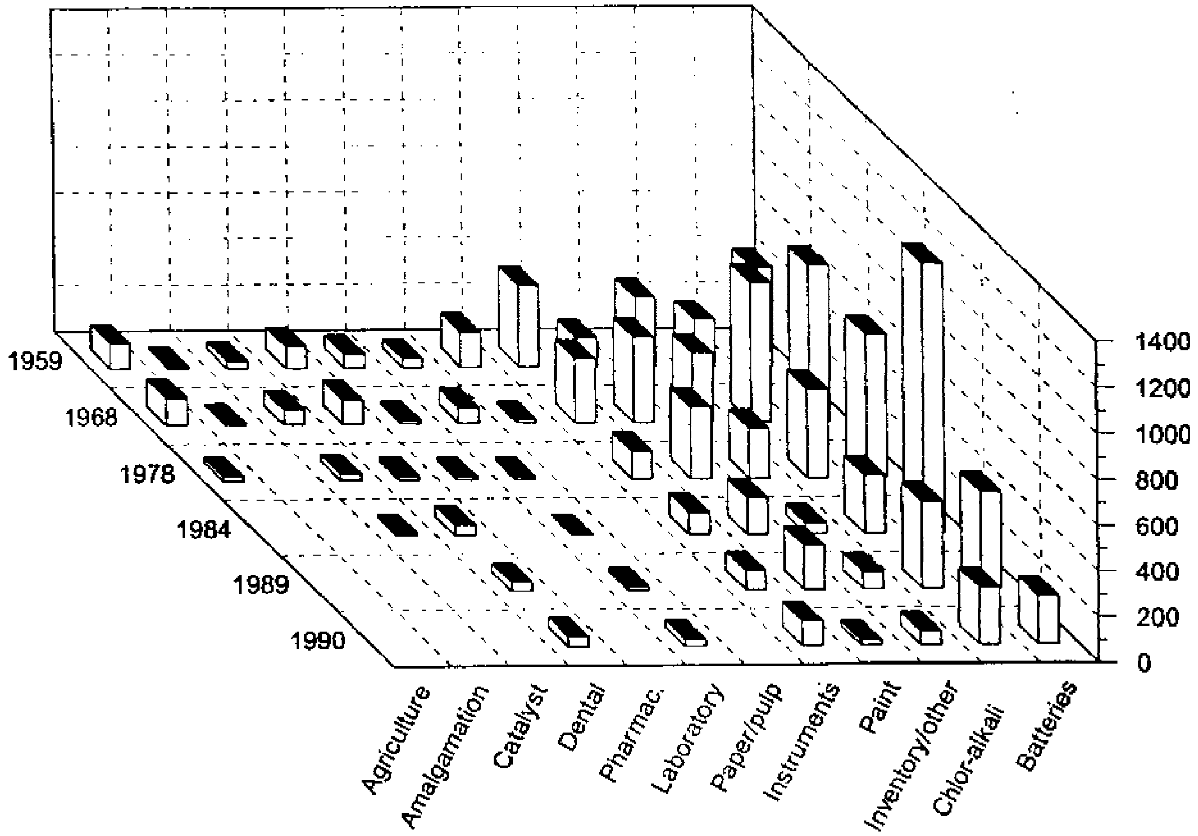


Figure 1.6 Use of Mercury in the United States

(metric tonnes per year, based on figures in Appendix 4)



CHAPTER 2

ENVIRONMENTAL RELEASES

2.1 Introduction

Environmental releases of mercury can be natural in origin (e.g. degassing from geological mineral deposits, volcanic activities) or can occur from anthropogenic sources such as industrial activities, energy production, and the use and disposal of consumer products.

2.2 Natural emissions

Natural emissions of mercury into air, water or land originate from soils and vegetation, and from forest fires, water surfaces, and geological sources (such as crustal weathering and degassing, volcanic activities, and earthquakes).

Various researchers have estimated the global annual natural emissions of mercury. Estimates vary over several orders of magnitude depending on the natural sources included in the estimate and the method of calculation. Estimates for natural emissions to air have ranged from 2500 to 125,000 tonnes per year. However, the concentrations of mercury in various compartments from natural and anthropogenic sources are highly variable. It would therefore be expected that the emissions to air would also be highly variable.

The most recent estimates are summarized in **Table 2.1**, which shows a reasonable agreement of the size of the natural, atmospheric emissions. The estimates vary depending on the relative contribution and importance placed on natural processes which emit mercury to the atmosphere.

According to Lindqvist et al. (1991) there are four main natural processes by which mercury is emitted to the atmosphere. These are:

- degassing from geological mineral deposits;
- emissions from volcanic activities;
- photoreduction of divalent mercury in natural waters;
- biological formation from methylmercury of elemental mercury or perhaps dimethylmercury.

Table 2.1 Estimates of Fluxes of Mercury to the Global Atmosphere

(metric tonnes of mercury per year)

Process	**Lindqvist et al. 1984**	**Nriagu and Pacyna 1988, Nriagu 1989**	**Fitzgerald 1986**	**Lindqvist et al. 1991**
Anthropogenic emissions	2000-10,000	3560 (910-6200)	2000	4500 (3000-6000)
Natural emissions	<15000	2500 (100-4900)	3000-4000	3000 (2000-9000)
Total present emissions	2000-<25,000	6060 (1010-11,100)	5000-6000	7500 (5000-15,000)

Other studies indicate that mercury can also be released by:

- volatilization from soil (Rundgren et al. 1992);
- seismic activities like earthquakes (Varshal et al. 1985);
- geothermal sources, including oceanic crust in connection with submarine volcanoes (Varekamp and Buseck 1986);
- crustal degassing in zones of high permeability created by faults and fractures (Stepanov and Vil d'Yayev 1984, Rasmussen 1993).

The relative significance of natural sources is reflected by the background content of mercury in the environment. With regard to land, the crustal average abundance of mercury is estimated at 0.08 mg/kg (Taylor 1964), which could be translated into approximately 32 million metric tonnes of mercury within the first metre of rock of the earth's continents (Garrett 1994). The concentration of the mercury in the crust varies according to a number of factors such as rock type, as shown in Appendix 5. There are limited estimates of mercury emissions to water, soil and vegetation from the natural weathering of the earth's crust. However, the concentration of mercury in various compartments (e.g. soil, peat, natural gas, etc.) in nature are significant and can be highly variable, as shown in Appendix 6. Therefore, annual estimates of mercury releases that do not account for natural sources can be considered to be low.

It is difficult to estimate the global importance of the geochemical activities as potential sources of releases of mercury to the environment, since the studies do not give global figures for mercury fluxes. There are many reported cases of high mercury concentrations in local hot spots (Appendix 6), for example the geothermal fields in Iceland. The annual flux from one field with such data was only 8 kg (Edner et al. 1991).

2.3 Anthropogenic emissions

2.3.1 Worldwide emissions

Due to the complexity of identifying anthropogenic sources and possible emission rates, estimates of worldwide emissions are extremely difficult to make. Using 1983 data, Nriagu and Pacyna (1988) estimated worldwide anthropogenic air emissions of mercury to be 3600 tonnes in 1983. This compares with anthropogenic emissions from all sources to water and soil, including atmospheric fall-out, of about 4600 and 8300 metric tonnes, respectively, (this does not include disposal of mine tailings, smelter slags and waste). On a global scale the major air inputs originate from coal combustion and incineration of solid waste products, whereas the major input to water is from manufacturing processes **(Table 2.2)**.

Nriagu and Pacyna (1988) looked at the man-induced mobilization of mercury into the biosphere (the terrestrial plus aquatic inputs), also for 1983, and estimated this total to be approximately 11,000 metric tonnes per year; this figure includes totals for mine tailings, smelter slags and waste, which equal approximately 1800 tonnes.

The latest comparable estimate for the global increase in mercury mobilization is 5000 metric tonnes per year (Lindqvist et al. 1991).

The latest global figures for natural and anthropogenic atmospheric emissions in Table 2.1 show that the two are of the same magnitude for the different authors. However, it must be assumed that the anthropogenic emissions have decreased since these estimates were calculated due to changes in technology and the reduction in mercury use.

2.3.2 Regional emissions

In a recent report prepared for the Commission of the European Communities (Maxson et al. 1991), the mercury emissions in the EC were estimated as shown in **Table 2.3**. While industrial activity and product use result in the greatest total release to all media, other activities may be higher within specific media (e.g. releases to air from fossil fuel burning are greater than from industrial activity or product use). Detailed information on emissions from the subactivities that make up the main activities can be found in Appendix 7.

Emissions to air in the United States (**Table 2.4**) closely follow the pattern in the European Union. As in the EU, emissions from fossil fuel burning (coal combustion) are the major anthropogenic emission source to the air. Emissions from municipal solid waste incineration in the United States are next in importance, as in the EU ("product use" in Table 2.3).

Table 2.2 Estimates of Worldwide Emissions of Mercury to the Atmosphere, Soil and Water in 1983

(metric tonnes per year, from Nriagu and Pacyna 1988 and Nriagu 1989)

Source category	**Atmosphere ***		**Water**		**Soil ****	
	min.	**max.**	**min.**	**max.**	**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	
Total inputs	910	6200	300	8800	1600	15000
Median	3560		4600		8300	
Mine tailings	no estimate		no estimate		550	2800
Smelter slags and wastes	no estimate		no estimate		50	280
Natural	100	4900	no estimate		no estimate	
Median	2500					
Total inputs to soils including mine tailings, smelter slags and wastes					**2200**	**18,000**

* Insignificant contributions to the atmosphere from: oil combustion, zinc-cadmium production, secondary non-ferrous production, steel and iron manufacturing, cement production, and mobile sources.

** Landfills included.

Table 2.3 Mercury Emissions in the EC by Sector in 1989

(metric tonnes per year, Maxson et al. 1991)

Source/ activity	Destination of immediate emissions			
	Air	Water	Land	Total
Non-ferrous*	21	1	54	77
Fossil fuels	76	<1	12	88
Industrial	29	8	207	244
Product use	62	17	202	281
Other**	8	8	54	70
Total	197	35	529	760
% total	26	5	69	100

* Includes mercury mining, secondary production and non-ferrous production and refining.

** Includes cremation, sludge waste disposal and dredging.

2.4 Contributing anthropogenic processes

2.4.1 Release from energy production

Coal contains mercury as a natural component in trace amounts (0.04-0.7 mg mercury/kg) (Sabbioni et al. 1983 and Meij 1991). Given the large quantity of coal burned in electrical power plants and in industrial, commercial and residential burners, considerable amounts of mercury are released to the environment.

Over the last ten to 15 years, a number of countries have shifted from the use of oil to the use of coal in energy production. This has resulted in a greater release of mercury due to higher mercury content in coal. The difference in mercury content of these two energy sources could be significant (Maxson et al. 1991). Due to the uncertainty over the actual concentration of mercury in oil, mercury emissions from oil burning in the EU could be anywhere from 2.4 to 24 tonnes (Maxson et al. 1991). Several countries have estimated the amount of mercury in coal and oil used for energy production (**Table 2.5**). The burning of peat and wood also releases mercury to the atmosphere.

Table 2.4 Annual Air Emissions in the United States

(US EPA 1993b)

Emission source	**Air release**		
	1988 metric tonnes	1988 %	1989 metric tonnes
Coal combustion	132	42.8	144
MSW incineration*	68	22.0	93
Industry	11.7	3.8	13.0
Copper smelting	41	13.3	n.i.
Sewage sludge incineration	36	11.7	n.i.
Other sources	20	6.4	n.i.
Total	**308.7**	**100.0**	

n.i. = no information

* An industry evaluation of existing municipal waste combustors in the United States arrived at somewhat lower figures. Taking into account the type of control technology used at each facility, industry estimates of mercury air releases from municipal solid waste (MSW) are about 40 metric tonnes/year.

Depending on the flue gas cleaning process for combustion sources, mercury will be released to the atmosphere or become a waste product to water and soil. Maxson et al. (1991) have assumed that 80 per cent of mercury in coal is emitted to air. With regard to both refuse incineration and coal combustion, even the best flue gas cleaning equipment will probably not remove more than 70 per cent of the mercury released during combustion (Meij 1991, Maxson et al. 1991).

2.4.2 Metal mining and production

Earlier non-ferrous metal processes released a significant amount of mercury to the atmosphere, but efficient gas cleaning facilities have reduced such emissions significantly (Lindqvist et al. 1991). However, as a result of the cleaning of the flue gases, a solid waste product is generated that has to be disposed of (**Table 2.6**). In 1988, US air emissions from the copper smelting industry were estimated to be 41 metric tonnes, comprising 13.3 per cent of total air releases (US EPA 1993b).

Table 2.5 Amount of Mercury as Natural Constituent in Coal and Oil Used for Energy Production

(metric tonnes per year)

Raw material	Denmark		Finland	Belgium		Germany	Sweden	Canada
	1982	1990	1987	1985	1990	1990	1988	1994
Coal	1.5	1.0	0.2	2.2-5.8	2.2-5.8	82.0-97.6	0.2	3.6*
Oil				1	1	<1.0		

* Preliminary estimate for 1994. The 1982 estimate was 9 metric tonnes of mercury produced from the burning of fossil fuels (coal, natural gas, oil and derivatives).

Mining of minerals for non-ferrous metal production produces considerable amounts of tailings containing mercury which need to be disposed of. The global estimate in 1983 was between 550 and 2800 metric tonnes (Nriagu and Pacyna 1988).

In Brazil mercury is still being used in gold mining, creating a mercury pollution problem. It has been estimated that in Brazil 58-96 tonnes is used annually for gold mining, with the consequent release of a minimum of 13 tonnes into the ecosystem (Malm et al. 1990). In some former gold mining areas, mercury contamination still causes local problems. It is reported (WHO 1989) that 50,000 people may be exposed around small-scale gold mining operations in Indonesia, Kampuchea, the Philippines, and Vietnam.

2.4.3 Other industrial processes, including the chlor-alkali industry

Table 2.7 shows the estimated mercury emissions for various industrial processes in the EC in 1989. As in the United States, the greatest number of emissions come from the chlor-alkali industry. The United States estimate for air emissions from industrial sources, excluding the chlor-alkali industry, was 11.7 metric tonnes in 1988 and 13.3 metric tonnes in 1989 (US EPA 1993b). For the EC, the total figure excluding the chlor-alkali industry was 6 metric tonnes in 1989. The majority of the waste from the chlor-alkali industry in the European Union is disposed of in accordance with the toxic waste directive.

In 1992 the chlor-alkali industry in the EC and Scandinavia (EURO CHLOR 1994) estimated that 100 metric tonnes was disposed of in accordance with the toxic waste directive, and that 17 tonnes was released to air and 3.5 tonnes to water, which is a further reduction in comparison with the figures in Table 2.7.

Until recent years, the chlor-alkali and pulp and paper industries released significant emissions of mercury, mostly as direct discharges to soil, water, and/or air. It is estimated that in 1960 the Swedish chlor-alkali industry released 10,000 kg mercury per year to the atmosphere. As a result of new emission control measures, by 1987 this total had been reduced to 400 kg per year (Lindqvist et al. 1991).

Table 2.6 Mercury Emissions in the EC from Mercury Mining, Secondary Production and Non-ferrous Industry in 1989

(metric tonnes per year, Maxson et al. 1991)

Source/activity	**Air**	**Water**	**Land**	**Total**
Mercury mining	10	?	20	30
Secondary production	5	<1	15	21
Non-ferrous production/ refining	6	1	19	26
Total	**21**	**1**	**54**	**77**

A chlor-alkali plant in New South Wales, Australia, disposes of approximately 10 tonnes of low level immobilised brine waste annually (CEPA 1994) where mercury release is regulated. There are only two remaining chlor-alkali plants in Canada that use mercury, and their air and water releases are regulated (Environment Canada 1994).

According to US EPA, the chlor-alkali industry is the largest industrial source of mercury releases in the United States. Referring to the 1990 US Toxics Release Inventory (TRI), the chlor-alkali facilities reported most of their quantities as off-site transfers – over 97 metric tonnes. The ultimate disposition of these off-site transfers is presumably via some form of approved hazardous waste disposal. Direct releases to water and land as reported are much lower than air releases. In 1990 the land releases are estimated to have been 540 kg, with 360 kg as direct water releases (US EPA 1993b).

Other industrial sources of emissions include:

- the iron and steel industry, in which some of this mercury can originate from metal scrap, e.g. electrical equipment in cars;

- the fertilizer industry, in which mercury is released during the production of sulphuric and phosphoric acid;

- the cement industry, which produces solid waste containing mercury.

In the past, the production of mercury compounds for use as seed dressings and in the pharmaceutical industry resulted in significant emissions to air and water (e.g. Kiørboe et al. 1983). Their use as seed dressing has recently diminished or been prohibited in many countries.

Table 2.7 Mercury Emissions in the EC from Industrial Processes in 1989

(metric tonnes per year, Maxson et al. 1991)

Industry	Air	Water	Land	Total
Chlor-alkali	23	5	150	178
Iron/steel	4	2	28	34
Fertilizer	<1	1	3	4
Cement	<1	no estimate	26	28
Total	**29**	**8**	**207**	**244**

2.4.4 Miscellaneous releases

In addition to the uses described above and emissions related to the manufacture, use, and disposal of mercury-containing products, there are a number of sources of environmental contamination by mercury. One example is the use of mercury in tooth fillings, which leads to release of mercury from dental clinics. Another is release from crematoria (mercury in tooth fillings).

2.4.5 Recycling

At present, recycling of mercury from scrap produced during industrial processes is quite extensive. However, recycling of mercury is not economical for most consumer products because mercury is only present in small amounts. One exception is the mercury oxide "button" battery – commonly used in hearing aids, medical devices and pagers – which contains sufficient quantities of mercury. Currently, at least three companies in the United States recover mercury from these batteries (Michigan Environmental Science Board 1993).

Many countries have collection systems for products which contain mercury (e.g. batteries); however, as indicated above, the recycling is not economical, and as a result the collected batteries are stored at hazardous waste disposal sites.

2.4.6 Incineration/landfill

When industrial solid waste and post-consumer products that contain mercury are not recycled or reused, they are generally disposed of in landfills or burned in incinerators. In the United States, the quantity of mercury in the municipal waste stream has been estimated as shown in **Table 2.8**. For many years household batteries have been the largest source of mercury in discarded or used products, followed by paint residues and pigments. Significant reductions in the level of mercury in products are foreseen by the year 2000, especially since mercury content in batteries is dropping dramatically (**Figure 2.1**). Mercury content in light switches is expected to increase throughout this decade (US EPA 1993c).

Generally it may be expected that similar municipal waste patterns exist in other OECD countries, with corrections for the different products used in each country.

In the United States, 68 metric tonnes of mercury was released to the air from municipal solid waste incinerators; this equals 22 per cent of air emissions (US EPA 1993b). An industry evaluation of existing municipal waste combustors arrived at a figure of 40 metric tonnes, amounting to 14 per cent of total air emissions taking into account the type of control technology used at each facility. **Table 2.9** shows a similar pattern in the EC in 1989, where air emissions from product use (municipal solid waste incineration only) are 62 metric tonnes, or 26 per cent of air emissions.

Without flue gas cleaning facilities, the majority of such mercury is emitted to the atmosphere. With flue gas cleaning facilities, most of the mercury will instead be found in the slag and fly ash and may create a disposal problem (Meij 1991, Maxson et al. 1991). The removal efficiency is the same as that for coal-fired power plants (see Section 2.4.1).

As the amount of land available for product disposal shrinks, many countries are turning towards incineration as a solution. As a result, mercury emissions from incineration are expected to increase. However, because most batteries are now produced without mercury it can be expected that the emissions from municipal waste incineration will decrease, even with an increase in the amount of waste incinerated. Besides, many countries require installation of new gas cleaning technology, which will further reduce the atmospheric emissions.

If the waste products are not incinerated, they have to be disposed of as solid waste in landfills. These landfills may give rise to the release of mercury to groundwater or to the atmosphere (Maxson et al. 1991). However, these emissions are difficult to quantify because too little is known about the processes which control the release of mercury.

Table 2.8 Discards of Products Containing Mercury in the Municipal Solid Waste Stream 1970-2000 (United States)

(discards before recovery in metric tonnes, US EPA 1993c)

Products	**1970**		**1980**		**1989**		**2000 estimate**	
	tonnes	%	tonnes	%	tonnes	%	tonnes	%
Household batteries	282	73.7	389.6	78.4	563.6	87.6	89.4	57.0
Electric lighting	17.3	4.5	22.0	4.4	24.2	3.8	37.2	23.7
Paint residues	27.4	7.2	24.2	4.9	16.5	2.6	0.4	0.3
Fever thermometers	11.1	2.9	23.3	4.7	14.8	2.3	15.2	9.7
Thermostats	4.8	1.3	6.4	1.3	10.2	1.6	9.3	6.0
Pigments	29.3	7.7	20.9	4.2	9.1	1.4	1.4	0.9
Dental uses	8.4	2.2	6.4	1.3	3.6	0.6	2.1	1.3
Special paper coatings	0.1	0	1.1	0.2	0.9	0.1	0	0
Mercury light switches	0.4	0.1	0.4	0.1	0.4	0.1	1.7	1.1
Film pack batteries	1.9	0.5	2.6	0.5	0	0	0	0
Total discards	**382.7**	**100**	**496.7**	**100**	**643.2**	**100**	**156.7**	**100**

Figure 2.1 Elimination of Mercury from General Purpose Batteries
(Europile, 1992)

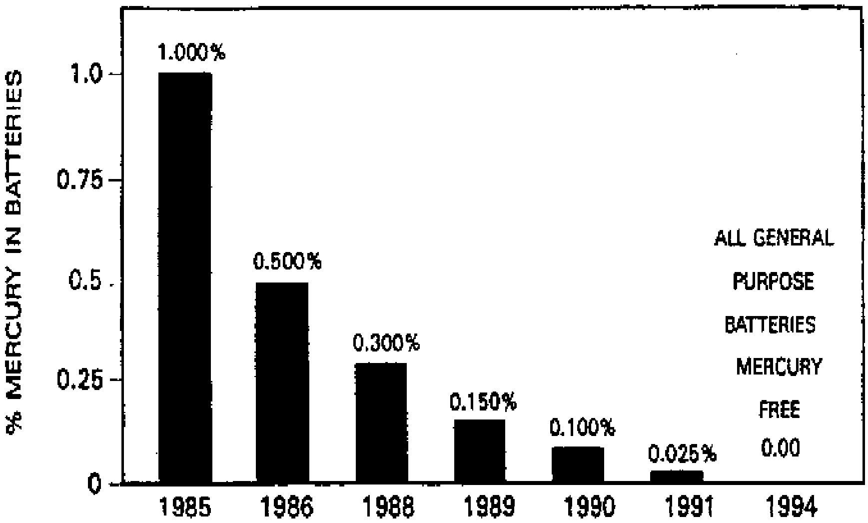


Table 2.9 Mercury Emissions in the EC from Product Use in 1989

(metric tonnes per year, Maxson et al. 1991)

Product use	**Air***	**Water**	**Land**	**Total**
Batteries	33	<1	100	133
Dental amalgams	8	14	24	46
Electrical lighting and equipment	10	<1	30	40
Measuring and control instruments	6	<1	19	25
Laboratory applications	1	1	6	8
Phosphate fertilizers	no estimate	no estimate	11	11
Industrial catalyst	4	<1	12	16
Total	**62**	**17**	**202**	**281**

* From municipal solid waste incineration. Only 8 per cent of incinerators have gas-cleaning technology.

CHAPTER 3

LINKAGES TO EXPOSURE

3.1 Introduction

Mercury is an element which, after its release into the environment, is distributed and continuously redistributed between and within environmental compartments. Compared with the other heavy metals, it is more mobile and therefore can be released to the atmosphere or to the aquatic environment again. Further, inorganic mercury may be methylated by microbial activity to a more toxic organic form that is also transferable in the environment, especially giving rise to bioaccumulation and biomagnification in living organisms.

Methylation of inorganic mercury takes place through the transfer of the carbanion CH_3^- to the Hg^{2+} ion, and occurs in nature through both biotic and abiotic processes. Mercury methylation occurs independently of whether the source of the Hg^{2+} ion is geological or anthropogenic.

3.2 Mercury concentrations

Typical concentrations of mercury in the different compartments in the environment are shown in **Table 3.1** (Craig 1988). High concentrations of mercury have been found in the different compartments around point sources and in sediments and biota in estuaries. Further information about mercury concentrations in different matrices can be found in Appendices 5 and 6. Further results will be discussed in the following sections.

3.3 Behaviour and occurrence in air

Natural and anthropogenic emissions of mercury to air contain many different chemical forms, depending on the type of diffuse sources. Elemental mercury and different forms of divalent mercury in gaseous or particulate phases are those most frequently emitted to air. The elemental mercury will add to the atmospheric background concentration and be spread widely by long-range transport. Apart from the magnitude of emissions, speciation is the most important factor in determining the radius of influence of mercury emissions from a point source (Lockeretz 1974). The divalent gasses and particulate matter will have a tendency to be deposited within 100 km or less of the points of emission (Semb and Pacyna 1988). Two recent studies showing increasing areal concentration gradients in proximity to a chlor-alkali plant and a municipal waste incinerator demonstrated a radius of impact of 1 km and 1.7 km, respectively (Calasans et al. 1993, Carpi et al. 1994). However, a smaller fraction of divalent and particulate mercury is distributed up to 1000-2000 km from the source areas and is also important for long-range transport of anthropogenic mercury (Lindqvist et al. 1991).

The emissions of oxidized divalent mercury compounds come from several sources, such as chlor-alkali plants and coal and refuse combustion. Elemental mercury is oxidized in the atmosphere by ozone and other oxidants.

The emissions of mercury, for example from land, crustal degassing, vegetation, and water surfaces, are assumed to be mainly elemental mercury. The dominant fraction of atmospheric mercury is generally assumed to be in the form of elemental mercury vapour, with a mean atmospheric residence time in the range of a few months to two years (Lindqvist and Rodhe 1985, Slemr et al. 1985). Mercury is removed from the atmosphere by dry and wet deposition. Particulate and oxidized forms may also be present in minor quantities compared with elementary mercury, but are much more readily removed from the air by wet or dry deposition.

The formation of the elemental mercury is expected to be due to both biotic and abiotic processes. Elemental mercury and dimethylmercury are the principal candidates for volatilization (emission and/or re-emission) into the atmosphere from natural waters and from soil surfaces.

Total vapour phase mercury fluxes (**Table 3.2)** from agricultural and forest soils are substantially smaller (by a factor of six) than those from the surface of a lake (Schroeder et al. 1989). The authors conclude that these measurements are still too few in number to draw general conclusions about mercury fluxes in the environment on a regional (or larger) scale. Kim et al. 1993 have measured mercury volatilization over polluted soil and natural soil (Table 3.2) and found significant differences in the fluxes. Over the natural soils both emission and deposition were measured. They conclude that the strength of mercury emissions can be greatly influenced by the combined effects of surface temperature, residence time of air masses over the source area, and turbulence conditions.

The volatilization of mercury from the ocean has been modelled by Bayens et al. 1991. They found very variable volatilization rates, depending on the wind speed. For example, at a wind speed of 2.8 metres/second they calculated a volatilization rate of 0.05-0.7 ng mercury/m^2/year, and at a wind speed of 54 metres/second they calculated a volatilization rate of 1.2-18 ng mercury/m^2/year. They further conclude that these data do not allow extrapolations on longer time scales, since they have no ideas about the evolution of the elemental mercury gradient from water to the atmosphere.

The magnitude of the emissions and deposition are similar, leading to a stable atmospheric concentration (Lindqvist and Rodhe 1985, Fitzgerald 1986). However, it has been demonstrated in a sampling programme for total gaseous mercury over the Atlantic Ocean that the concentrations of total mercury in the atmosphere increased from 1977 to 1990 by 1.46 per cent ± 0.17 per cent per year in the northern hemisphere, and by 1.17 per cent ± 0.16 per cent in the southern hemisphere (Slemr and Langer 1992). The authors suggest that this indicates anthropogenic sources, rather than natural sources, are at present more important in the mercury cycle.

Table 3.1 Typical Mercury Concentrations in the Environment

Description	Range of concentration
Soils 1) & 2)	
Igneous rocks and minerals	0.1-0.03 mg/kg d.w.
Agricultural soils	0.03-0.15 mg/kg d.w.
Contaminated soils (anthropogenic)	10 to 100 times higher
Input to soils:	
From fertilizers	< 10 g/km^2/year
From sludge (EEC Directive)	max. 1 g/km^2/year
Agricultural seed dressing	20 g/km^2/year
Air 2)	
Remote areas	1-4 ng/m^3
Industrial	20-50 ng/m^3
Water 3)	
Total mercury:	
Groundwater	0.5-15 ng/litre
Lake water	2-12 ng/litre
Rivers, dissolved	0.01-6 ng/litre
Seawater, dissolved	0.05-3 ng/litre
Methylmercury: 4)	
Run-off water	0.4-0.6 ng/litre
Lake water	0.04-0.8 ng/litre
Rain water	<0.5-0.6 ng/litre
Sediments 3)	
Uncontaminated	0.05 mg/kg d.w.
Normal	0.2-0.4 mg/kg d.w.
Contaminated (anthropogenic)	1->20 mg/kg d.w.
Biota 3)	
Freshwater fish	0.2-7 mg/kg f.w.
Marine fish	0.01-1.5 mg/kg f.w.
Tuna, swordfish	0.3-7 mg/kg f.w.
Shellfish	0.01-1 mg/kg f.w.
Plants 2)	
Plants	<0.1 mg/kg f.w.

d.w. = dry weight; f.w. = fresh weight

(Further data can be found in Appendices 5 and 6)

Main reference: Craig 1988
1) Rundgren et al. 1992
2) Lindqvist et al. 1991
3) Cossa et al. 1990
4) Lee and Iverfeldt 1991

Table 3.2 Emissions of Mercury from Soil and Water Surfaces

Site	ng mercury/m^2/ hectare	Reference
Contaminated floodplain, Oak Ridge, Tennessee, USA	15-160	Kim et al. 1993
Natural soil, Oak Ridge, Tennessee, USA	-6-6*	Kim et al. 1993
Forest soil, Sweden	1.1 ± 0.4	Schroeder et al. 1989
Lake surface, Sweden	6.3 ± 3.6	Schroeder et al. 1989

* indicating both emission and deposition fluxes

Other researchers have found that the natural background level of mercury is not constant over large geographic areas such as the Atlantic Ocean (Buat-Menard and Duce 1987). Factors which could cause natural variations include geological sources, such as the Icelandic geysers studied by Edner et al. (1991), or temperature. Lantzy and McKenzie (1979) comment that the effect of oceanic and atmospheric temperatures on biological activity and condensation could cause increased volatilization from equatorial waters and increased deposition in higher latitudes.

Although there are no reliable deposition measurements to demonstrate a decrease in mercury deposition over the last 20-30 years, a decrease in deposition as a result of various control measures might have been expected in various countries during recent years. Recently atmospheric deposition measurements have been performed in both Europe and North America, and similar deposition rates have been found (**Table 3.3**).

Measurement of historical deposition rates of mercury in Scandinavia using core samples of peat bogs has demonstrated that the deposition rates in southern Scandinavia have increased from about 10 to 30 µg/m^2/year since the beginning of this century. It was not yet possible to verify that the decreased emissions resulted in a decrease in recent deposition (Jensen and Jensen 1991). A number of studies (geochemical prospecting) indicate that peat bog geochemistry (including that of "raised bogs") tends to reflect local factors such as bedrock geochemistry or glacial drift geochemistry (Armands 1967, Salmi 1967, Toverud 1977, Coker and DiLabio 1979, DiLabio and Coker 1982, DiLabio 1983). According to these studies, it would be difficult to use peat bog cores to distinguish between anthropogenic and natural sources of mercury.

In a study from Norway (Steinnes et al. 1993), it was concluded that the average ratio of surface peat relative to pre-industrial levels is 4.1 ± 2.8 for the 13 bogs sampled. In the southeastern part, a ratio of about 10 is observed. Measurements of mosses have demonstrated that the mercury deposition in the southern and southwestern part is more than twice the level in remote areas. Moss data have been compared with atmospheric deposition measurements at nearby localities, where a similar trend has been found. Steinnes (1993)

Table 3.3 Wet Deposition of Mercury

Site	µg mercury/m^2/year	Reference
Southern Baltic Sea, Europe	5.9-14.8	Jensen and Iverfeldt 1994
Great Lakes, USA	6.2-9.9	Hoyer et al. 1993
Upper Midwest, USA	5.1-10.0	Sorensen et al. 1994

also indicates that the contribution of mercury from soil degassing is a complicating factor in the use of mosses as atmospheric biomonitors. Carpi et al. (1994) overcame this problem by using bags of homogenized sphagnum moss to map the concentration gradient around an industrial point source. In this study, the radius of impact of mercury was found to be only one to two kilometres.

3.4 Behaviour and occurrence in the aquatic environment

The input of mercury to the aquatic environment is the result of direct point source emissions, natural processes releasing mercury, and atmospheric fall-out from natural or anthropogenic sources.

The main source of mercury to the open oceans is wet deposition. The concentrations in the ocean surface waters are elevated in the northwest Atlantic compared with the northwest Pacific (0.8 and 0.4 ng/litre, respectively) (Gill and Fitzgerald 1987). This may indicate an influence from industrial activities in the northern hemisphere. The mean residence time for mercury in the open oceans is relatively short in geochemical terms, about 350 years (Gill and Fitzgerald 1988). The oceans are a major source of mercury to the atmosphere due to evasional fluxes of elemental mercury (Kim and Fitzgerald 1986).

The major negative effect of environmental pollution by mercury is the biomagnification of methylmercury in the aquatic food chains. This has led to a very large effort in trying to determine the regulating mechanisms for the uptake of methylmercury in fish.

Mercury in the aquatic environment is accumulated in biota in increasing concentrations with increasing age, as well as at higher trophic levels (Nriagu 1979). Methylmercury, with a biological half-life on the order of one year, is strongly retained in biota. The ratio between methylmercury and total mercury increases with trophic level, resulting in high concentrations of methylmercury in fish, e.g. flounder and cod, with the highest concentrations in long-living fish such as tuna (Bacci 1989).

A key question in regard to the aquatic ecosystem is the source of methylmercury entering the food chain. In-lake methylation of inorganic mercury in the water column or sediments is a possible internal source (Fitzgerald et al. 1991). The new data on methylmercury fluxes generated at the Lake Gårdsjön catchments (Hultberg et al. 1994, Lee et al. 1994) point to the importance of the external methylmercury load on the lake biota. Studies in Canada (Rasmussen 1993) have shown that local geological sources, like faults, can be a local mercury source giving rise to increased local levels of mercury in the soil, vegetation, sediments and fish. However, there is still a need to elucidate conclusively the quantitative flux from different sources to the fish.

Recent studies in both Scandinavia and North America (Lindqvist et al. 1991) have shown that mercury deposited earlier, especially in forest soils, becomes mobile in increasing amounts by association with organic matter and is transported via run-offs from the drainage area to surface waters. The transport is closely related to the transport of humic matter in the water (Meili 1991). This gives rise to elevated mercury concentrations in the food chain, including fish, even in lakes which are remote from direct sources (Lathrop et al. 1991).

Studies, especially in Canada, have shown that land with high naturally elevated mercury levels, and which has been flooded with water, has a high rate of methylmercury production associated with the degradation of submerged organic material (Hecky et al. 1991), which in turn gives rise to high accumulation of mercury in fish (Verdon et al. 1991). This can be a potential problem in any area with elevated mercury levels from natural or anthropogenic sources.

Sediments are a major sink for mercury. However, because of the dynamic exchange with the overlying water column and methylation of mercury in sediments by microorganisms, mercury can be released again to both water and the atmosphere. Methylation also gives rise to uptake of methylmercury in biota. While the net production of methylmercury is very low (i.e. 0.1 per cent of total mercury in the upper part of marine sediment in a year) (Bacci 1989), it can still have significant environmental consequences due to bioaccumulation.

There is evidence that mercury is mobile in sediments. Vertical profiles of mercury and other trace elements in sediment columns commonly display surface enrichment near the sediment/water interface. This surface enrichment of mercury and many other elements develops whether the source of the element is natural or anthropogenic. Several biogeochemical processes lead to element enrichment in surface sediments, including remobilization and upward migration in the sediment column, adsorption onto oxides in surface sediments, organic decay, and biogeochemical reactions near the sediment/water interface (Farmer 1992, Coker et al. 1979). Studies in Canada (Rasmussen 1993) have suggested that surface enrichment of mercury occurs in lake sediments remote from point sources as a result of natural processes. Krabbenhoft and Babiarz (1992) also recognised the significance of natural processes in the mobility of mercury in sediments.

Measurements of mercury in Swedish freshwater sediments have indicated a five-fold increase in mercury deposition and mercury concentration, as compared with background conditions in southern Sweden, and approximately a doubling in the northernmost part of the country (Johansson et al. 1991). Sediments from the deep basins in the Baltic Sea show a three-fold increase over the concentrations in pre-1850 samples (Madsen and Larsen 1986). Analysis of sediments from lakes in northeastern Minnesota, remote from direct inputs of mercury, suggest that mercury deposition has increased by a factor of about 3.5 over the last 150 years. Because the increase is spatially constant across northeastern Minnesota, atmospheric pollution appears to be responsible for the increase (Pratt 1990, Swain and Helwig 1989).

3.5 Behaviour and occurrence in soil

Mercury occurs naturally in soils due to decaying vegetation, groundwater, till or bedrock weathering, and can be introduced by atmospheric deposition (from natural or anthropogenic sources) and anthropogenic activities.

It is generally believed that the major input of mercury to soil is atmospheric fall-out. Other inputs are the spreading of sewage sludge and fertilizers. The use of organic mercury compounds in seed dressing is another significant source, although its use has diminished over the latest ten to 20 years.

There is a dynamic exchange of volatile mercury compounds between the atmosphere and the soil, mainly in the form of elemental mercury, which is easily absorbed by soil organic matter, though it is available for re-emission from certain soils. Microbial and biochemical processes are important for the exchange rates. Methylmercury may be quite stable, and some methylation is known to occur by chemical and microbial processes involving inorganic mercury compounds in soil (Rundgren et al. 1992).

Because of the very high affinity of several mercury compounds to soil organic matter, leaching losses to subsoil horizons, groundwater or surface water are thought to be small for normal soils. In nearly neutral soils, sometimes low in organic matter, iron and clay minerals may be important absorption sites. In acid soils, transport of the carrier organic matter constituents is almost a prerequisite for mercury mobility, as the stability of complexes of organic matter with mercury is high at low pH values (pH 3-5). This explains the earlier mentioned mobility of mercury in acidified forest soils (Rundgren et al. 1992).

Mercury accumulates in soil invertebrates starting at only slightly elevated concentrations in the soil (Rundgren et al. 1992). The accumulation of mercury in plants increases with increasing soil mercury concentration. Soil types have a considerable influence on this process. Generally, the highest concentrations of mercury have been found in the roots; but translocation to other organs (e.g. leaves) has also been identified (WHO 1989).

The long-range transport and increased deposition of anthropogenic mercury have markedly increased the mercury content, by about five to ten times, in organic rich top soil layers in central Europe and southern Scandinavia (Lambersdorf et al. 1991, and Lindqvist et al. 1991). Mercury in soil acts as a powerful toxin, particular in respect of microorganisms. There are indications that the regionally enhanced concentrations of mercury in these areas may have an adverse effect on microbiological processes, and indirectly on the recycling of important nutrients and on tree vitality (Godbold 1991, and Tyler 1992).

Recent Swedish mercury balances for some watersheds have demonstrated that the present atmospheric deposition onto forest soils is much higher, on average about three to ten times higher, than the output via run-off waters. The highest ratios are found in the southern parts of Sweden. Obviously, mercury is still accumulating in forest soils at present atmospheric deposition rates, giving rise to increased concentrations in these soils, despite the fact that emissions of mercury to air have been drastically reduced in Sweden during the last decades (Lindqvist et al. 1991). It is estimated that total inputs to soils in Scandinavia have to be reduced by 80 per cent of the present deposition rates for equilibrium to be attained in the entire profile of both cultivated and forest soils (Lindqvist et al. 1991).

Nater and Grigal (1992) have studied the regional trends in mercury distribution across the Great Lakes in the north central United States by measuring mercury both in forest floor, surface mineral soil and deeper mineral soils. They have found a significant gradient in the concentrations of mercury in forest floor and surface mineral soil along a transect of forested sites across the north central United States from northwestern Minnesota to eastern Michigan. This gradient is accompanied by parallel changes in wet sulphate deposition, suggesting, according to the authors, that the regional variation in mercury content is due to deposition of anthropogenic mercury. A clear west-to-east gradient persists, with the highest net change in the easternmost sites and also, after correction for the background concentrations, in the deeper minerals soils.

Natural sources influence the mercury cycle in remote areas. The direct capture of mercury vapour by soil, and the reverse process, the volatilization of soil mercury, result in a net transfer of mercury from soil to air under natural conditions (Lockeretz 1974). In addition, mercury levels in plants and soil organic matter may reflect increased proximity to natural geological sources (Dunn 1987).

A study in a remote non-polluted area in Wisconsin showed that 92-96 per cent of mercury deposited on the land surface is retained by the soil (Krabbenhoft and Babiarz 1992), and 4-8 per cent is transferred to the aquatic compartment.

3.6 Example of mass balance for mercury input

To give an indication of the importance of the different inputs to the aquatic environment, an estimate of the input of mercury to the North Sea is given in **Table 3.4**. According to the Second International Conference on the Protection of the North Sea (1987), riverine inputs, atmospheric fall-out, and dumping of dredged material are the major inputs, accounting for more than 90 per cent of the inputs to the North Sea. Based on this, in order to obtain a reduction in the inputs to the aquatic environment, it is essential to reduce these three sources of mercury pollution. It is assumed that the input pattern in the North Sea reflects the situation in the industrialized part of the world.

3.7 IPCS data on pathways to human exposure

The three key components for understanding human exposure to mercury are the daily intake of mercury via exposure source (e.g. food), the form of the mercury that enters the body (e.g. methylmercury), and the retention of a particular form of mercury in the body (**Table 3.5)**. (The significance of the form of the mercury and of retention for human health effects is discussed in Chapter 4.)

The intake of mercury from the ambient atmosphere has been estimated by assuming that the concentration of total mercury is 2 ng/m^3 and that 75 per cent is present as elemental mercury vapour, 5 per cent as inorganic mercury compounds, and 20 per cent as methylmercury. The daily intake of each form of mercury was estimated by assuming a daily ventilation of 20 m^3, and the amount absorbed was estimated by assuming that 80 per cent of the inhaled elemental

Table 3.4 Input of Mercury to the North Sea 1983-86

(metric tonnes per year)

Source	**Minimum**	**Maximum**
River inputs	20	21
Direct discharges	5	5
Atmospheric	10	30
Dumpings		
Dredgings	17	17
Sewage sludge	0.6	0.6
Industrial waste	0.2	0.2
Incineration at sea	trace	trace
Total (rounded)	**50**	**75**

vapour, 50 per cent of the inorganic mercury compounds, and 80 per cent of the methylmercury was absorbed across the pulmonary membranes (WHO 1976).

Mercury intake from drinking water was estimated by assuming a daily water intake of 2 litres and an average concentration of 25 ng/litre. It was also assumed that all the mercury is in the inorganic form. Methylmercury has been found in a few samples taken from bodies of natural water, but there have been no reports of methylmercury in drinking water (WHO 1990).[2]

For elemental mercury, the major source of exposure – and also the one with the highest retention – is dental amalgams. It is important to note that no daily intake is detected for inorganic mercury compounds or methylmercury for dental amalgams.

Experimental studies have shown that mercury is released from amalgam restorations in the mouth as vapour. The release rate of this mercury vapour is increased, for example, by chewing. Several studies have correlated the number of dental amalgam fillings or amalgam surfaces with the mercury content in tissues from human autopsy, as well as in samples of blood,

---

[2] It is usually assumed that $Hg(OH)_2$ and $HgCl_2$ are the predominant species in surface waters. However, organic mercury has been reported to represent 22-37 per cent of the total mercury in lake, river and tap water from the Ottawa, Canada, area (Schintu et al. 1989).

Table 3.5 Estimated Average Daily Intake and Retention (figures in brackets) of Total Mercury and Mercury Compounds (µg/day) in the General Population Not Occupationally Exposed to Mercury[a] (WHO 1990)

Exposure	**Elemental mercury vapour**	**Inorganic mercury compounds**	**Methylmercury**
Air	0.030 (0.024)	0.002 (0.001)	0.008 (0.0064)
Food			
Fish	0	0.600 (0.042)	2.4 (2.3)
Non-fish	0	3.6 (0.25)	0
Drinking water	0	0.050 (0.0035)	0
Dental amalgams	3.8-21 (3-17)	0	0
Total	**3.9-21 (3.1-17)**	**4.3 (0.3)**	**2.41 (2.31)**

[a] See text for assumptions underlying the calculations of average daily intake and retention.

urine and plasma. Both the predicted mercury uptake from amalgam and the observed accumulation of mercury show substantial individual variation. It is therefore difficult to make accurate quantitative estimations of the mercury release and uptake by the human body from dental amalgam tooth restorations (WHO 1991). Values given are the estimated average daily intake; the figures in parentheses represent the estimated
amount retained in the body of an adult.

For inorganic mercury compounds, the major source of exposure is through non-fish food where retention is low.

It is clear that fish and fish products are the dominant source of human exposure to methylmercury, even when low fish consumption is assumed. Daily methylmercury intake can vary over a wide range, depending on the amount of fish consumed and the methylmercury concentration in the fish (**Table 3.6**). A number of communities have been identified where individual intake of fish exceeded 200 µg mercury/day (WHO 1976, 1980; Turner et al. 1980; GESAMP 1986). As it is assumed that 80 per cent of this mercury is methylmercury and that 95 per cent of the methylmercury is absorbed, the absorbed amount of methylmercury (>153 µg/day) will, in these cases, dominate the daily mercury exposure. On the basis of general population surveys of fish consumption, it was estimated that in Australia 0.9 per cent of the population ate more than 1000 g fish/week and that this corresponded to about 20 µg mercury/day (WGMF 1980). In the United States, surveys of fish consumption (US Dept. of Commerce 1978) were used to estimate that, with no regulatory control of the mercury content of marketed fish, 99.81 per cent of all respondents had an upper limit mercury intake lower than their personal allowable daily intake (based on 30 µg mercury/day for a 70 kg person) at a 95 per cent level. An action level of 1 mg mercury/kg in fish for regulatory control would increase this percentage to 99.87 per cent, and an action level of 0.5 mg mercury/kg would increase it to 99.89 per cent.

Table 3.6 Intake of Methylmercury (µg/day) from Fish with Various Methylmercury Levels and at Various Rates of Fish Consumption[a] (WHO 1990)

Consumption of fish (g/day)	**Level of methylmercury in fish (µg/kg fresh weight)**				
	200	500	1000	2000	5000
5	1	2.5	5	10	25
20	4	10	20	40	100
100	20	50	100	200	500
300	60	150	300	600	1000
1000[b]	200	500	1000	2000	5000

[a] Adapted from WHO (1980).

[b] Data from GESAMP (1986) indicate that maximum intake of fish may equal 1000 g/day.

CHAPTER 4

INTERNATIONAL AND NATIONAL POSITIONS ON THE RISKS FROM MERCURY

This chapter contains an assessment of the risks of mercury, taken from International Programme on Chemical Safety (IPCS) Environmental Health Criteria documents.

Also presented in this chapter are country statements, provided by OECD Member countries, in regard to national positions on risks from mercury. These statements essentially present the rationale for any actions the country has taken or contemplates taking to address the effects associated with exposure to mercury. The risk assessments and risk characterisations that have led countries to take action have a national character. Countries develop positions on the need for risk reduction activities only after they have analysed the hazard and the significance of certain exposures and have factored in local social, economic and political considerations. These positions are usually arrived at after considerable debate on the numerous factors involved, and thus are not consistent across Member countries.

4.1 International position (IPCS)

4.1.1 IPCS Environmental Health Criteria 86: Mercury – Environmental Aspects

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. The main objective of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment. The Environmental Health Criteria documents prepared by IPCS contain the collective views of an international group of experts and do not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Labour Organisation, or the World Health Organization.

The text below is taken directly from Chapter 9 of IPCS Environmental Health Criteria Document No. 86: **Mercury – Environmental Aspects*.***

EVALUATION

In evaluating the environmental hazard of mercury it is necessary to extrapolate from laboratory experiments to ecosystems. This must be done with extreme caution for the following reasons:

(i) Speciation of mercury and its adsorption to environmental components such as soil, sediment, organic matter, and biota limit its availability to organisms in the environment.

(ii) Environmental variables such as temperature, pH and chemical composition of water, soil type, and geology have been shown in limited studies on a narrow range of species to affect both uptake and effect of mercury. There is insufficient information to fully assess the probable affects of, for example, tropical conditions and acid precipitation.

(iii) There are few data measuring mercury availability to organisms. Most data represent nominal or total metal concentration, rather than that component which could be taken up by organisms. True exposure is, therefore, difficult to assess.

(iv) There are limited data on the behaviour of mixtures of metals from controlled experimental work; organisms in the environment are exposed to mixtures.

(v) Experimental work seldom, if ever, is conducted on species or communities that are either representative or key components of natural communities and ecosystems. Studies do not consider all of the interactions between populations and all of the environmental factors affecting these populations.

It is probable that subtle disturbances to the community occur at much lower concentrations than those suggested in laboratory studies on acute effect, perhaps as much as one order of magnitude lower.

The Marine Environment

Marine aquatic organisms at all levels accumulate mercury into tissues. This mercury is retained for long periods if it is in an organic form. A number of factors affect the susceptibility of aquatic organisms to mercury. These include the life-cycle stage (the larval stage being particularly sensitive), the development of tolerance, water temperature, and salinity. Some incidents of severe pollution have resulted in the death of fish at that time. Few follow-up studies have been reported so that it is impossible to assess the long-term hazards. Toxic effects have been produced experimentally only at concentrations much higher than those found in the non-polluted marine environment. Furthermore, most of the studies have been on acute lethality and have used inorganic mercury compounds in the main. Birds, particularly coastal species or those eating prey that feed in estuaries, have been affected by mercury contamination. It has adversely affected breeding and may have influenced population stability.

The Freshwater Environment

Mercury compounds are acutely toxic to freshwater microorganisms. Using photosynthesis and/or growth as parameters, the NOTEL (No-observed-toxic-effect-level) for inorganic mercury lies between 1 and 50 µg/litre, depending on the organism, density of cells in culture, and experimental conditions. Diversity of species in mixed culture may be affected by 40 µg mercuric chloride/litre. For organomercury compounds, the NOTEL is 10-100 times lower.

Aquatic plants sustain damage after exposure to inorganic mercury at concentrations of 800 to 1200 µg/litre. Organomercury produces toxic effects at concentrations 10-100 times lower.

Many aquatic invertebrates are sensitive to mercury toxicity, particularly as larvae. Organic mercury compounds are toxic at concentrations 10 to 100 times less than inorganic mercury. For the most sensitive species, *Daphnia magna*, the NOTEL for reproductive impairment is 3 µg/litre for inorganic mercury and < 0.04 µg/litre for methylmercury.

Freshwater fish show lethal responses to mercury in acute nominal concentrations from approximately 30 µg/litre. Larvae under the same static conditions are 10 times more sensitive. In flow-through tests, fish are up to 100 times more sensitive. In both static and low-through tests, organomercury compounds are approximately 10 times more toxic than inorganic compounds. The NOTEL for the most sensitive parameters may be well below 0.01 µg/litre.

Aquatic developmental stages of amphibia show sensitivity to mercuric compounds similar to that of fish.

The Terrestrial Environment

Based on the current state of knowledge, it is not possible to determine the true exposure or concentration of mercury available to terrestrial organisms. It can, however, be stated that exposure via soil, soil water, and food is most important; exposure via open water and air is less important.

Mercury has been shown, in laboratory studies, to be toxic to terrestrial organisms over a broad range of concentrations. However, most of these studies are at high exposure levels (birds) or environmentally unrealistic exposure routes (hydroponic culture of plants).

It can be stated that acute effects would not be seen in terrestrial plants growing in natural soils, nor in terrestrial birds or mammals, other than by exposure to mercurials used as fungicidal seed dressings. Other effects seen in birds derive from mercury in the marine environment.

4.1.2 IPCS Environmental Health Criteria 101: Methylmercury

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. The main objective of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment. The Environmental Health Criteria documents prepared by IPCS contain the collective views of an international group of experts and do not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Labour Organisation, or the World Health Organization.

The text below concerning the risks to human health from compounds of monomethylmercury is taken directly from Chapter 1 of IPCS Environmental Health Criteria Document No. 101: **Methylmercury** ***(WHO 1990). It examines the data that have become available since the publication of Environmental Health Criteria No. 1:*** **Mercury** ***(WHO 1976).***

Identity, Physical and Chemical Properties, Analytical Methods

The solubility of methylmercury compounds in water varies greatly and depends on the nature of the anion. Most are soluble in water but much less soluble in non-polar solvents. They generally have appreciable vapour pressures at room temperature. Mercurials, including alkylmercurials, exhibit high affinities for sulfhydryl groups.

Bloods samples for analysis should be taken by venipuncture, avoiding devices using mercury-containing preservatives. Current methods are capable of measuring mercury in 1- to 5-ml samples of whole blood, even in the case of non-exposed individuals. Hair is useful in assessing exposure to methylmercury in the diet and may be sampled as single or bunched strands. The single-strand procedure requires both sensitive analytical methods and the determination of the growth phase of the hair.

The method of choice for determining total mercury in environmental and biological samples is flameless atomic absorption spectroscopy (detection limits, 0.5-4.0 ng/g). Neutron activation analysis serves as a sensitive reference method. Gas chromatography is used to determine methylmercury directly (detection limit, 1.0 ng/g sample).

Sources of Human and Environmental Exposure

Environmental methylmercury arises largely, if not solely, from the methylation of inorganic mercury. The major source of atmospheric mercury is the natural degassing of the earth's crust, amounting to 2700-6000 tonnes per year. Deposition of atmospheric mercury, leaching from rocks, and anthropogenic sources all add to the mercury burden in bodies of water, but the exact contribution of each source is indeterminable.

About 10 000 tonnes of mercury per year are mined, subject to considerable year-to-year variation. Other important man-made sources are fossil fuels combustion, smelting of sulfide ores, production of cement, and refuse incineration. The total man-made global release of mercury to the atmosphere is approximately 2000-3000 tonnes per year, i.e., less than the natural emissions. Man-made emissions pose the greatest risk when they are released in confined areas.

Mercury continues to be used in the production of caustic soda and chlorine, and it is widely used in the electrical industry for lamps, controls, rectifiers, batteries and switches, as well as in the dental progression. Environmental losses can also occur from its continued use in antifouling and mildew-proofing paints, in seed dressings, and in the extraction of gold.

Environmental Transport, Distribution, and Transformation

There is a well recognized global cycle for mercury, whereby emitted mercury vapour is converted to soluble forms (e.g., Hg^{++}) and deposited by rain onto soil and water. Mercury vapour has an atmospheric residence time of between 0.4 and 3 years, whereas soluble forms have residence times of a few weeks. Transport in soil and water is thus limited, and it is likely that deposition will occur within a short distance.

The change in speciation of mercury from inorganic to methylated forms is the first step in the aquatic bioaccumulation process. Methylation can occur non-enzymically or through microbial action. Once methylmercury is released, it enters the food chain by rapid diffusion and tight binding to proteins. As a result of food-chain biomagnification, highest levels are found in the tissue of such predatory species as freshwater trout, pike, walleye, bass and ocean tuna, swordfish, and shark. The bioconcentration factor, i.e., the ratio of the concentration of methylmercury in fish tissue to that in water, is usually between 10 000 and 100 000. Levels of selenium in the water may affect the availability of mercury for uptake in aquatic biota. Reports from Sweden and Canada suggest that methylmercury concentrations in fish may increase following the construction of artificial water reservoirs.

Environmental Levels and Human Exposure

The general population is primarily exposed to methylmercury through the diet. However, air and water, depending upon the level of contamination, can contribute significantly to the daily intake of total mercury. In most foodstuffs, mercury is largely in the inorganic form and below the limit of detection (20 µg mercury/kg fresh weight). However, fish and fish products are the dominant source of methylmercury in the diet, and levels greater than 1200 µg/kg have been found in the edible portions of shark, swordfish, and Mediterranean tuna. Similar levels have been found in pike, walleye, and bass taken from polluted fresh waters.

It has been estimated that humans have a daily intake of about 2.4 µg methylmercury from all sources, and a daily uptake of approximately 2.3 µg.[3] The total daily intake of *all* forms of mercury from all sources has been estimated to be 6.7 µg, with an added burden of 3.8 to 21 µg of mercury of mercury vapour from dental amalgams, if present. The level of mercury in fish, even for humans consuming only small amounts (10-20 g of fish/day), can markedly affect the intake of methylmercury. The consumption of 200 g of fish containing 500 µg mercury/kg will result in the intake of 100 µg mercury (predominantly methylmercury). This amount is one-half of the recommended provisional tolerable weekly intake (WHO 1989).

---

[3] See Table 3.5 in Chapter 3 of this OECD Risk Reduction Monograph.

Kinetics and Metabolism

Methylmercury in the human diet is almost completely absorbed into the bloodstream and distributed to all tissues within about 4 days. However, maximum levels in the brain are only reached after 5-6 days. In humans, blood to hair ratios are about 1:250, with appreciable individual variation. Similarly, large individual differences are seen in cord to maternal blood mercury ratios, the levels generally being higher in cord blood. Species differences exist in the distribution of methylmercury between red blood cells and plasma (about 20:1 in humans, monkeys, and guinea-pigs, 7:1 in mice, and <100:1 in rats).

Methylmercury is converted to inorganic mercury in experimental animals and humans. The duration of the exposure and the interval after its cessation, determine the fraction of total mercury present in tissues in the Hg^{++} form. In humans, after high oral intakes of methylmercury for 2 months, the following values were reported (percentage of total mercury in tissues as inorganic mercury): whole blood, 7 per cent; plasma, 22 per cent; breast milk, 39 per cent; urine, 73 per cent; liver, 16-40 per cent.

The rate of excretion of mercury in both laboratory animals and humans is directly proportional to the simultaneous body burden and can be described by a single-compartment model with a biological half-time, in fish-eating humans, of 39-70 days (average approximately 50 days). Lactating females have significantly shorter half-times for mercury excretion than non-lactating ones.

Mercury half-times in hair closely follow those in blood but with wider variation (35-100 days, average 65 days). Suckling mice are incapable of excreting methylmercury, but they abruptly change to the adult rate of excretion at the end of the suckling period.

In the case of continuous exposure, a single-compartment model with a 70-day half-time predicts that the whole-body steady state (where intake equals excretion) will be attained within approximately one year and that the maximum amount accumulated will be 100 times the average daily intake. The validity of the single-compartment model is supported by the reasonable agreement between predicted and observed blood concentrations of methylmercury in single-dose tracer studies, single-dose fish intake experiments, and studies involving the extended controlled intake of methylmercury from fish. It is also supported by results from the longitudinal hair analysis of individuals with very high intakes of methylmercury.

Mean reference values for total mercury in commonly used indicator media are: whole blood, 8 µg/litre; hair, 2 µg/g; urine, 4 µg/litre, and placenta, 10 µg/kg wet weight. Long-term fish consumption is the major determinant of methylmercury and, usually, total mercury levels in blood. For example, in communities in which there is a long-term daily consumption of 200 µg mercury/day from fish, blood mercury levels are approximately 200 µg/litre and corresponding hair levels about 250 times higher (50 µg/g hair).

Effects on Experimental Animals and *In Vitro* Systems

In every animal species studied, the nervous system is a target of methylmercury, fetuses appearing to be at higher risk than adults. Concerning effects on the nervous system, animal studies reported since 1976 provide further support to the mechanistic models used to evaluate the available data in humans.

Methylmercury is fetotoxic in mice (single dose of 2.5-7.5 mg/kg); teratogenic in rats, and adversely affects the behaviour of monkey offspring (mercury doses of 50-70 µg/kg per day before and during pregnancy). It also affects spermatogenesis in mice (1 mg mercury/kg as methylmercury).

Effects on Man – Mechanism of Action

The effects of methylmercury on adults differ both qualitatively and quantitatively from the effects seen after prenatal or, possibly, early postnatal exposures. Thus, effects on the mature human being will be considered separately from the effects on developing tissues.

The clinical and epidemiological evidence indicates that prenatal life is more sensitive to the toxic effects of methylmercury than is adult life. The inhibition of protein synthesis is one of the earliest detectable biochemical effects in the adult brain, though the sequence of events leading to overt damage is not yet understood. Methylmercury can also react directly with important receptors in the nervous system, as shown by its effect on acetylcholine receptors in the peripheral nerves. In the case of prenatal exposure, the effects of methylmercury seem to be quite different and of a much more general basic nature. It affects normal neuronal development, leading to altered brain architecture, heterotopic cells, and decreased brain size. Methylmercury may also be exerting an effect, perhaps through inhibition of the microtubular system, on cell division during critical stages in the formation of the central nervous system.

Since 1976, a wealth of data has been reported on dose-effect and dose-response relationships in humans. It has been derived from in-depth studies on populations exposed to methylmercury through mass poisonings or through the consumption of fish containing varying levels of methylmercury. Again, prenatal and adult data will be considered separately in view of the differences, both qualitative and quantitative, in effects and dose-response relationships.

In adults, the reported relationships between response and body burden (hair or blood mercury concentrations) are essentially the same as those reported in Environmental Health Criteria 1: Mercury (WHO 1976). No adverse effects have been detected with long-term daily methylmercury intakes of 3-7 µg/kg body weight (hair mercury concentrations of approximately 50-125 µg/g). Pregnant women may suffer effects at lower methylmercury exposure levels than non-pregnant adults, suggesting a greater risk for pregnant women.

Severe derangement of the developing central nervous system can be caused by prenatal exposure to methylmercury. The lowest level (maximum maternal hair mercury concentration during pregnancy) at which severe effects were observed was 404 µg/g in the Iraqi outbreak and the highest no-observed-effect level for severe effects was 399 µg/g. Fish-eating populations in Canada and New Zealand have also been studied for prenatal effects, but exposure levels were far below those that caused effects in Iraq and no severe cases were seen.

Evidence of psychomotor retardation (delayed achievement of developmental milestones, a history of seizures, abnormal reflexes) was seen in the Iraqi outbreak at maternal hair levels below those associated with severe effects. The extrapolation of data suggested that one of these effects (motor retardation) rose above the background frequency at maternal hair levels of 10-20 µg/g. The Canadian study reported that abnormal muscle tonne or reflexes were positively associated with maternal hair levels in boys but not in girls (the highest maternal hair level during pregnancy was 23.9 µg/g). The New Zealand study reported evidence of developmental retardation (according to the Denver Test) in 4-year-old children at average maternal hair mercury levels during pregnancy within the range of 6-86 µg/g (the second highest value was 19.6 µg/g). The New Zealand mercury values should be multiplied by 1.5 to convert to maximum maternal hair levels in pregnancy.

Conclusions

The general population does not face a significant health risk from methylmercury. Certain groups with a high fish consumption may attain a blood methylmercury level (about 200 µg/litre, corresponding to 50 µg/g of hair) associated with a low (5 per cent) risk of neurological damage to adults.

The fetus is at particular risk. Recent evidence shows that at peak maternal hair mercury levels above 70 µg/g there is a high risk (more than 30 per cent) of neurological disorder in the offspring. A prudent interpretation of the Iraqi data implies that a 5 per cent risk may be associated with a peak mercury level of 10-20 µg/g in maternal hair.

There is a need for epidemiological studies on children exposed *in utero* to levels of methylmercury that result in peak maternal hair mercury levels below 20 µg/g, in order to screen for those effects only detectable by available psychological and behavioral tests.

4.1.3 IPCS Environmental Health Criteria 118: Inorganic Mercury

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. The main objective of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment. The Environmental Health Criteria documents prepared by IPCS contain the collective views of an international group of experts and do not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Labour Organisation, or the World Health Organization.

The text below is taken directly from Chapters 1 and 12 of IPCS Environmental Health Criteria document No. 118: Inorganic Mercury (WHO 1991).

SUMMARY AND CONCLUSIONS

This [Environmental Health Criteria document] concentrates primarily on the risk to human health from inorganic mercury, and examines research reports that have appeared since the publication of Environmental Health Criteria 1: Mercury (WHO, 1976). In the period since 1976, new research data has become available for two main health concerns related to inorganic mercury, i.e. mercury in dental amalgam and in skin-lightening soaps. The emphasis in this monograph is on exposure from these two sources, but the basic kinetics and toxicology are reviewed with all aspects of inorganic mercury in mind.

Human health concerns related to the global transport, bioaccumulation, and transformation of inorganic mercury almost exclusively arise from the conversion of mercury compounds into methylmercury and exposure to methylmercury in sea-food and other food. The global environmental and ecological aspects of inorganic mercury have been summarized in this [Environmental Health Criteria document]. More detailed descriptions may be found in Environmental Health Criteria 86: Mercury – Environmental Aspects (WHO, 1989) and Environmental Health Criteria 101: Methylmercury (WHO, 1990).

Identity

Mercury exists in three states: Hg^0 (metallic); Hg_2++ (mercurous) and Hg++ (mercuric). It can form organometallic compounds, some of which have found industrial and agricultural uses.

Physical and Chemical Properties

Elemental mercury has a very high vapour pressure. The saturated atmosphere at 20^o C has a concentration over 200 times greater than the currently accepted concentration for occupational exposure.

Solubility in water increases in the order: elemental mercury < mercurous chloride < methylmercury chloride < mercuric chloride. Elemental mercury and the halide compounds of alkylmercurials are soluble in non-polar solvents.

Mercury vapour is more soluble in plasma, whole blood, and haemoglobin than in distilled water, where it dissolves only slightly. The organometallic compounds are stable, although some are readily broken down by living organisms.

Analytical Methods

The most commonly used analytical methods for the quantification of total and inorganic mercury compounds are atomic absorption of cold vapour (CVAA) and neutron activation. Detailed information relating to analytical methods are given in Environmental Health Criteria 1: Mercury (WHO, 1976) and Environmental Health Criteria 101: Methylmercury (WHO, 1990).

All analytical procedures for mercury require careful quality control and quality assurance.

Analysis, Sampling, and Storage of Urine

Flameless atomic spectrophotometry is used in routine analysis for various media. Particular care must be take when choosing the anticoagulant used for blood sampling in order to avoid contamination by mercury compounds. Special care must also be taken in the sampling and storage of urine, since bacterial growth can change the concentration of the numerous forms of mercury that may be present. Addition of hydrochloric acid or bactericidal substances and freezing the sample are the best methods to prevent alteration of urine samples. Correction of concentration by reference to urine density or creatinine content are recommended.

Analysis and Sampling of Air

Analytical methods for mercury in air may be divided into instant reading methods and methods with separate sampling and analysis stages. Instant reading methods can be used for the quantification of elemental mercury vapour. Sampling in acid-oxidizing media or on hopcalite is used for the quantification of total mercury.

The cold vapour atomic absorption (CVAA) technique is the most frequently used analytical method.

Sources of Human and Environmental Exposure

Natural Occurrence

The major natural sources of mercury are degassing of the earth's crust, emissions from volcanoes, and evaporation from natural bodies of water.

The natural emissions are of the order of 2700-6000 tonnes per year.

Sources due to Human Activities

The world-wide mining of mercury is estimated to yield about 10 000 tonnes/year. These activities lead to some losses of mercury and indirect discharges to the atmosphere. Other important sources are fossil fuels combustion, metal sulfide ore smelting, gold refining, cement production, refuse incineration, and industrial applications of metals.

The specific normal emission from a chloralkali plant is about 450 g of mercury per ton of caustic soda produced.[4]

The total global amount and release of mercury due to human activities, to the atmosphere has been estimated to be up to 3000 tonnes/year.

Uses

A major use of mercury is as a cathode in the electrolysis of sodium chloride. Since the resultant chemicals are contaminated with mercury, their use in other industrial activities leads to a contamination of other products. Mercury is used in the electrical industry, in control instruments in the home and industry, and in laboratory and medical instruments. Some therapeutic agents contain inorganic mercury. A very large amount of mercury is used for the extraction of gold.

Dental silver amalgam for tooth filling contains large amounts of mercury, mixed (in the proportion of 1:1) with alloy powder (silver, tin, copper, zinc). Copper amalgam, used mostly in paediatric dentistry, contains up to 70 per cent mercury and up to 30 per cent copper. These uses can cause exposure of the dentist, dental assistant, and also of the patients.

Some dark-skinned people use mercury-containing creams and soap to achieve a lighter skin tone. The distribution of these products is now banned in the EEC, in North America, and in many African countries, but mercury-containing soap is still manufactured in several European countries. The soaps contain up to 3 per cent of mercuric iodine and the creams contain ammoniated mercury (up to 10 per cent).

---

[4] The figure 450 g of mercury is based on data from six plants in one developing country using older technology. Regulations in most industrialized countries now limit such emissions to between 2 and 5 g of mercury/tonne of chlorine.

Environmental transport, distribution, and transformation

Emitted mercury vapour is converted to soluble forms and deposited by rain onto soil and water. The atmospheric residence time fro mercury vapour is up to 3 years, whereas soluble forms have a residence time of only a few weeks.

The change in speciation of mercury from inorganic to methylated forms is the first step in the aquatic bioaccumulation process. This can occur non-enzymically or through microbial action. Methylmercury enters the food-chain of predatory species where biomagnification occurs.

Human exposure

The general population is primarily exposed to mercury through the diet and dental amalgam. Depending on the concentrations in air and water, significant contributions to the daily intake of total mercury can occur. Fish is a dominant source of human exposure to methylmercury. Recent experimental studies have shown that mercury is released from amalgam restorations in the mouth as vapour. The release rate of this mercury vapour is increased, for example, by chewing. Several studies have correlated the number of dental amalgam fillings or amalgam surfaces with the mercury content in tissues from human autopsy, as well as in samples of blood, urine, and plasma. Both the predicted mercury uptake from amalgam and the observed accumulation of mercury show substantial individual variation. It is, therefore, difficult to make accurate quantitative estimations of the mercury release and uptake by the human body from dental amalgam tooth restorations. Experimental studies in sheep have examined in greater detail the distribution of mercury released from amalgam restorations.

Use of skin-lightening soap and creams can give rise to substantial mercury exposure.

Occupational exposure to inorganic mercury has been investigated in chloralkali plants, mercury mines, thermometer factories, refineries, and in dental clinics. High mercury levels have been reported for all these occupational exposure situations, although levels vary according to work environment conditions.

Kinetics and metabolism

Results of both human and animal studies indicate that about 80 per cent of inhaled metallic mercury vapour is retained by the body, whereas liquid metallic mercury is poorly absorbed via the gastrointestinal tract (less than 1 per cent). Inhaled inorganic mercury aerosols are deposited in the respiratory tract and absorbed, the rate depending on particle size. Inorganic mercury compounds are probably absorbed from the human gastrointestinal tract to a level of less than 10 per cent on average, but there is considerable individual variation. Absorption is much higher in newborn rats.

The kidney is the main depository of mercury after the administration of elemental mercury vapour or inorganic mercury compounds (50-90 per cent of the body burden of animals). Significantly more mercury is transported to the brain of mice and monkeys after the inhalation of elemental mercury than after the intravenous injection of equivalent doses of the mercuric form. The red blood cell to plasma ratio in humans is higher (≥ 1) after administration of elemental mercury than mercuric mercury and more mercury crosses the placental barrier. Only a small fraction of the administered divalent mercury enters the rat fetus.

Several forms of metabolic transformation can occur:

- oxidation of metallic mercury to divalent mercury;
- reduction of divalent mercury to metallic mercury;
- methylation of inorganic mercury;
- conversion of methylmercury to divalent inorganic mercury.

The oxidation of metallic mercury vapour to divalent ionic mercury is not fast enough to prevent the passage of elemental mercury through the blood-brain barrier, the placenta, and other tissues. Oxidation in these tissues serves as a trap to hold the mercury and leads to accumulation in brain and fetal tissues.

The reduction of divalent mercury to Hg^0 has been demonstrated both in animals (mice and rats) and humans. The decomposition of organomercurials, including methylmercury, is also a source of mercuric mercury.

The faecal and urinary routes are the main pathways for the elimination of inorganic mercury in humans, although some elemental mercury is exhaled. One form of depletion is the transfer of maternal mercury to the fetus.

The biological half-time, which only lasts a few days or weeks for most of the absorbed mercury, is very long, probably years, for a fraction of the mercury. Such long half-times have been observed in animal experiments as well as in humans. A complicated interplay exists between mercury and some other elements, including selenium. The formation of a selenium complex may be responsible for the long half-time of a fraction of the mercury.

Reference and normal values

Limited information from deceased miners shows mercury concentrations in the brain, years after cessation of exposure, of several mg/kg, with still higher values in some parts of the brain. However, lack of quality control of the analysis makes these data uncertain. Among a small number of deceased dentists, without known symptoms of mercury intoxication, mercury levels varied from very low concentrations up t a few hundred µg/kg in the occipital lobe cortex and from about 100 µg/kg to a few mg/kg in the pituitary gland.

From autopsies on subjects not occupationally exposed but with a varying number of amalgam fillings, it seems that a moderate number (about 25) of amalgam surfaces may on average increase the brain mercury concentration by about 10 µg/kg. The corresponding increase in the kidneys, based on a very limited number of analyses, is probably 300-400 µg/kg. However, the individual variation is considerable.

Mercury levels in urine and blood can be used as indicators of exposure provided that the exposure is recent and relatively constant, is long-term, and is evaluated on a group basis. Recent exposure data are more reliable than those quoted in Environmental Health Criteria 1: Mercury (WHO, 1976). The differences may in part be explained by different sampling technique for evaluating air exposure. An exposure of 40 µg mercury/m^3 of air will correspond to about 15-20 µg mercury/litre of blood. However, interference from methylmercury exposure can make it difficult to evaluate exposure to low concentrations of inorganic mercury by means of blood analysis. A way to overcome the problems is to analyse mercury in plasma or analyse both inorganic mercury and methylmercury. The problem of interference from methylmercury is much smaller when analysing urine, as methylmercury is excreted in the urine to only a very limited extent.

Effects in humans

Acute inhalation exposure to mercury vapour may be followed by chest pains, dyspnoea, coughing, haemoptysis, and sometimes interstitial pneumonitis leading to death. The ingestion of mercuric compounds, in particular mercuric chloride, has caused ulcerative gastroenteritis and acute tubular necrosis causing death from anuria where dialysis was not available.

The central nervous system is the critical organ for mercury vapour exposure. Subacute exposure has given rise to psychotic reactions characterized by delirium, hallucinations, and suicidal tendency. Occupational exposure has resulted in erethism as the principal feature of a broad ranging functional disturbance. With continuing exposure a fine tremor develops, initially involving the hands. In the milder cases erethism and tremor regress slowly over a period of years following removal from exposure. Decreased nerve conduction velocity has been demonstrated in mercury-exposed workers. Long-term, low-level exposure has been associated with less pronounced symptoms of erethism.

There is very little information available on brain mercury levels in cases of mercury poisoning, and nothing that makes it possible to estimate a no-observed-effect level or a dose-response curve.

At a urinary mercury excretion level of 100 µg mercury/g creatinine increases the incidence of some less severe toxic effects that do not lead to overt clinical impairment. IN a few studies tremor, recorded electrophysiologically, has been observed at low urine concentrations (down to 25-35 µg/g creatinine). Other studies did not show such an effect. Some of the exposed people develop proteinuria (proteins of low relative molecular mass and microalbuminuria). Appropriate epidemiological data covering exposure levels corresponding to less than 30-50 µg mercury/g creatinine are not available.

The exposure of the general population is generally low, but may occasionally be raised to the level of occupational exposure and can even be toxic. Thus, the mishandling of liquid mercury has resulted in severe intoxication.

The kidney is the critical organ following the ingestion of inorganic divalent mercury salts. Occupational exposure to metallic mercury has long been associated with the development of proteinuria, both in workers with other evidence of mercury poisoning and in those without such evidence. Less commonly, occupational exposure has been followed by the nephrotic syndrome, which has also occurred after the use of skin-lightening creams containing inorganic mercury, and even after accidental exposure. The current evidence suggests that this nephrotic syndrome results from an immunotoxic response. Until recently, effects of elemental mercury vapour on the kidney had been reported only at doses higher than those associated with the onset of sings and symptoms from the central nervous system. New studies have, however, reported kidney effects at lower exposure levels. Experimental studies on animals have shown that inorganic mercury may induce auto-immune glomerulonephritis in all species tested, but not in all strains, indicating a genetic predisposition. A consequence of an immunological etiology is that, in the absence of dose-response studies for groups, of immunologically sensitive individuals, it is not scientifically possible to set a level for mercury (e.g., in blood or urine) below which (in individual cases) mercury-related symptoms will not occur.

Both metallic mercury vapour and mercury compounds have given rise to contact dermatitis. Mercurial pharmaceuticals have been responsible for Pink disease in children, and mercury vapour exposure may be a cause of "Kawasaki" disease. In some studies, but not in others, effects on the menstrual cycle and/or fetal development have been reported. The standard of published epidemiological studies is such that it remains an open question whether mercury vapour can adversely affect the menstrual cycle or fetal development in the absence of the well-known signs of mercury intoxication.

Recently, there has been an intense debate on the safety of dental amalgams and claims have been made that mercury from amalgam may cause severe health hazards. Reports describing different types of symptoms and signs and the results of the few epidemiological studies produced are inconclusive.

PREVIOUS EVALUATIONS BY INTERNATIONAL BODIES

The human risks of inorganic mercury compounds were previously evaluated in Environmental Health Criteria 1: Mercury (WHO 1976). More recent evaluations by the International Programme in Chemical Safety (IPCS) have dealt mainly with the health risks of methylmercury exposure (WHO 1990). A WHO review of the occupational health risks of inorganic mercury (WHO 1980) and an IPCS review of the environmental aspects of mercury (WHO 1989) have been published. The recommended health-based occupational exposure limit for metallic mercury vapour (WHO 1980) is 25 μg mercury/m^3 air (TWA, long-term exposure) and 500 μg mercury/m^3 air (peaks, short-term exposure). The equivalent value for long-term exposure to inorganic mercury compounds is 50 μg mercury/m^3 air (TWA) (WHO 1980). A maximum individual urine mercury concentration of 50 μg/g creatinine has also been recommended (WHO 1980).

Regulatory standards established by national bodies in various countries and in the European Community are summarized in the data profile of the International Register of Potentially Toxic Chemicals (IRPTC, 1987).

4.2 National positions

Australia

The Australian Market Basket Survey examines the levels of contaminants and pesticides in the Australian diet. The 1984 survey found negligible levels of mercury in all foods except for fish and other seafood. Surveys since 1984 have only examined the level of mercury in seafood. The results for cooked battered fish bought in Australian Capital Cities were as shown in **Table 4.1**.

Table 4.1 The Australian Market Basket Surveys for Cooked Battered Fish in mg mercury/kg (CEPA 1994)

Year	**1984**	**1985**	**1990**
Median	0.06	0.07	0.07
90th percentile	0.31	0.41	0.57

There is no statistical difference between the results for the three surveys.

Australia has established maximum permissible levels in food as follows:

Fish, crustaceans, molluscs (sampled according to prescribed methods)	0.5 mg mercury/kg (mean level)
Fish, crustaceans, molluscs (not sampled according to prescribed methods)	1.0 mg mercury/kg (mean level)
Water	0.001 mg mercury/l
Drinking chocolate, powder	0.03 mg mercury/kg

The National Occupational Health and Safety Commission (NOHSC) exposure standard for aryl and inorganic mercury is currently 0.1 mg/m^3 time weighted average (TWA) over eight hours (skin absorption). The occupational health surveillance requirements for mercury and the exposure standards are under review.

The Australian Water Quality Guidelines set a maximum of 0.1 μg/l mercury for the protection of aquatic ecosystems. The limit for drinking water is 1 μg/l. For other uses, such as irrigation or livestock, the guideline is 2 μg/l. Disposal of wastes at sea requires a permit to be issued under the Environment Protection (Sea Dumping) Act 1981, which specifies that the waste should not contain more than 0.00015 per cent total mercury (dry weight).

The Government of Victoria has set Design Ground Level Concentrations (CLCs) for air emissions of mercury:

organic 0.0003 mg/m^3

inorganic 0.017 mg/m^3.

Denmark

General remarks

Mercury has no known beneficial effects whatsoever and is considered to be one of the most problematic substances used by society. It is well proven to cause very serious toxic effects in humans. Also, in the environment, toxic effects are seen. In addition, due to mercury's ability to bioaccumulate in the food chain, it could lead to serious toxic effects in humans. Another very important fact is that mercury once released into circulation in the environment is non-degradable and will stay in circulation for a very long time, providing opportunity for toxic effects throughout this period.

General policy

For these reasons the exposure of humans should be kept to an absolute minimum. This can be obtained only by minimizing the use of mercury for all purposes, thereby minimizing both direct exposure and indirect exposure through environmental pollution.

Earlier it was thought that emission control of industrial sources was sufficient to reduce exposure to acceptable levels. It has become more and more obvious that this is not sufficient. This "cleaning" strategy results in waste streams from industry. Besides, products containing mercury are still being produced, giving rise to diffuse mercury pollution during use and mercury-containing waste after use.

The Netherlands

Risks and risk groups

Risks to man

Elemental mercury

- *exposure via air*

Exposure to elemental mercury occurs primarily through inhalation. Occasional measurements indicate that the background concentration in the atmosphere is 1.5-2 ng/m^{-3}, and 1.5-5 ng/m^{-3} on a national scale.

There are no reliable data on effects of exposure levels resulting in creatinine concentrations in urine of less than 30 to 50 µg mercury/g^{-1} of creatinine. These concentrations roughly correspond to a mercury concentration in the air of 25-40 µg/m^{-3}. According to the WHO, it cannot be ruled out that mild effects occur in sensitive persons at these exposure levels (WHO 1991).

The atmospheric concentrations of elemental mercury in the Netherlands are, therefore, a factor of 1000 lower than the levels at which such effects could occur. Based on these data it is concluded that harmful effects are not expected in the general population at these exposure levels.

- *exposure via amalgam*

The general population can be exposed to elemental mercury from amalgam. Acute exposure to higher mercury concentrations (5-10 µg/m^{-3}) occurs during dental treatment (removal of old fillings with a drill, and burnishing of fillings), while chronic exposure to lower (but elevated) mercury concentrations occurs as a result of corrosion and wear during the functioning of the filling.

For the patient, the mercury-vapour concentrations in the surgery and during treatment are, considering the brief and occasional nature, probably of less consequence than the chronic exposure to lower concentrations of elemental mercury from the fillings. Mercury from amalgam can enter the body by several routes: through the oral mucous membranes, inhalation through the mouth, and ingestion of mercury dissolved in saliva. Estimates of the amount of mercury vapour and inorganic mercury released from amalgam fillings and the extent to which it is absorbed are inaccurate. This is due to, among other things, measurement problems and a multitude of individual factors (such as chewing gum, and the number of amalgam fillings). The WHO has estimated an exposure of 3-17 µg of mercury from amalgam per day (WHO 1991). However, according to Dutch investigators (Schuurs and Davidson, 1993 draft) and a recent American report (DHHS 1993), the exposure is lower. The Dutch researchers have estimated a total exposure of 2.3 µg per day. The American report estimated that seven to ten amalgam fillings result in an additional mercury exposure of 1 to 5 µg per day.

There has been much discussion recently about the risks of mercury released from amalgam fillings. In 1991, the WHO concluded that the reports, in which all kinds of complaints and symptoms have been attributed to mercury, do not permit a conclusion about the cause of the complaints. Two epidemiological studies could not demonstrate a relation between the number of amalagam fillings and the prevalence of all kinds of specific complaints and symptoms on a population basis. However, the researchers did not rule out the possibility of an association on an individual basis. Two recent Dutch studies (Schuurs and Davidson 1993; Allard 1993) concluded that there is insufficient scientific evidence that mercury from amalgam constitutes a health risk. A recent American report (DHHS 1993) arrived at the same conclusion, but did comment that adequate epidemiological studies on effects of exposure levels due to amalgam fillings are not available.

In summary, it can be stated that there is insufficient evidence for the existence of a relation between the number of amalgam fillings and an increased prevalence of all kinds of complaints and symptoms, except in individual cases (allergy, auto-immunity). The following calculation can serve as an illustration: suppose that 100 per cent of the highest estimated mercury exposure from amalgam (17 μg per day; WHO IPCS 1991) would be inhaled "normally", then this means a mercury concentration in air of 17/20 (20 m^3 = air intake per day) x 1000 ng = 850 ng/m^{-3}. This is less than 4 per cent of the concentration at which, according to the WHO, effects can occur in sensitive persons. Based on this approach, mercury from amalgam does not constitute a risk to the general population.

Inorganic mercury compounds

In calculating the daily exposure to inorganic mercury, it has been assumed that mercury in all foodstuffs, excluding fish and fish products, is present in the inorganic form. The average and maximum exposure via food has been estimated to be 3.9 and 15.5 μg per day, respectively (corresponding to 0.065 and 0.25 $\mu g/kg^{-1}$ body weight per day, respectively, for a 60 kg adult).

The intake from drinking water is negligible (mercury concentration in drinking water is <0.05 $\mu g/l^{-1}$). Assuming that all the mercury in drinking water is in the inorganic form, the average additional intake would be <0.10 μg per person per day (at an average consumption of 2 l of drinking water per day). Given the concentration of inorganic mercury in the ambient air, the intake via inhalation is also negligible.

With regard to inorganic mercury, the available data for oral exposure are insufficient for deriving a toxicological recommended level. On the basis of a comparison with organic mercury compounds (taking into account a lower absorption and lower toxicity; arbitrarily, a factor of 10) it can be assumed that a daily oral intake of 5 $\mu g/kg^{-1}$ body weight (corresponding to 300 μg per day) does not result in adverse effects. This approach is supported by data from experimental animal studies.

Based on the above data it is concluded that, even assuming the maximum exposure to inorganic mercury via food and drinking water, adverse effects are not likely to occur in the general population. Assuming the maximum exposure, there is a factor of 20 between exposure and the concentration at which (possibly) no harmful effects are expected. It should be noted that this margin can be smaller for infants because of a possible higher absorption. On the other hand, infants will be exposed to mercury to a smaller extent (milk).

Methylmercury

In calculating the average and maximum daily exposure to methylmercury, it has been assumed that all the mercury in fish and fish products is present as methylmercury and that all other foodstuffs and drinking water do not contain organic mercury. The average and maximum exposure to methylmercury via food has been calculated to be 0.73 and 1.92 µg per day, respectively (corresponding to 0.012 and 0.032 µg/kg^{-1} body weight per day for a 60 kg adult). It is assumed that not more than about 20 per cent of mercury in the ambient air is present as methylmercury. This means an additional methylmercury intake of at most about 0.02 µg per person per day (assuming an ambient air mercury concentration of 1.5-5 ng/m^{-3}; 80 per cent retention; air intake 20 m^{3}). This intake is considered to be negligible compared to the oral exposure.

The provisional tolerable weekly intake (PTWI) for methylmercury is 200 µg for adults (excluding pregnant and lactating women and their children), corresponding to 0.5 µg/kg^{-1} body weight per day. These data show that the exposure levels are at least a factor of 10 lower than the PTWI, so that harmful effects are not expected at the current methylmercury levels.

For pregnant and lactating women and the developing child, an intake of 40 µg per week (corresponding to 0.1 µg/kg^{-1} body weight per day) will possibly not cause adverse effects. These data show that the maximum exposure is a factor of 3 lower than the PTWI, so that harmful effects are not expected. It should be noted, however, that the consequences of a possibly diminished ability of infants to excrete methylmercury are not known at the present time.

Aquatic environment

A "maximum tolerable concentration" (MTC) for dissolved mercury (inorganic plus organic) in surface water, both fresh and salt, of 0.008 µg/l^{-1} has been derived. This concentration in Dutch fresh surface waters corresponds to 0.05 µg/l^{-1} total mercury. This MTC is based on toxicity data for methylmercury, which is more toxic and is bioaccumulated to a greater degree than inorganic mercury. After a strong decrease in the concentration of mercury in the seventies, the current concentrations of mercury seem to stabilise for dissolved mercury at 0.01 µg.1^{-1} and for total mercury at 0.05 µg/l^{-1}. These concentrations refer to inorganic mercury plus methylmercury in both fresh and sa.1lt water (State and coastal waters). The MTC mentioned above is exceeded particularly in regional waters: in 1990, a total mercury concentration of > 0.5 µg/l^{-1} was measured at 7 per cent of the locations sampled in these waters, a factor of 10 higher than the MTC. However, less than 10 per cent of the total mercury in surface waters is present as methylmercury, whereas the MTC has been derived from data for methylmercury. Based on this information, it is concluded that the risk to aquatic ecosystems is limited, certainly in the State and coastal waters (the percentage of the total mercury present as methylmercury in shallow regional waters is not known). In view of the data underlying the MTC, this limited risk applies also to predators (both birds and mammals) which feed on fish and/or other aquatic organisms.

A MTC for inorganic plus organic mercury in bottom sediments of 0.9 mg/kg^{-1} dry weight has been derived. The MTC is exceeded in a considerable proportion of the freshwater sediments: a concentration of 1.6-15 and > 15 mg/kg^{-1} dry weight was measured in 20 per cent and 1 per cent, respectively, of the sediment samples from fresh State waters and regional waters, resulting in a risk to organisms living on and in the bottom (benthic organisms). It should be noted that the MTC mentioned above (derived using the equilibrium-partitioning method) probably overestimates the actual risk. This is because sulphide is present in sediments, which combines with inorganic mercury to form insoluble mercuric sulphide, so removing a large proportion of the inorganic mercury. It is expected that the bioavailability of this form of mercury is nil or very low. It must be noted, however, that mercuric sulphide is slowly converted into Hg^{2+} under aerobic conditions; the rate of this process depends on the extent to which the anaerobic part of the sediment is affected by (bio)perturbation (burrowing activities of bottom organisms; influence of wind and current). In addition, mercury is methylated in bottom sediments. Therefore the risk of effects depends on the rates of these two processes, which will vary from location to location.

Terrestrial environment

A MTC for total mercury (inorganic plus organic) in soil of 1.0 mg/kg^{-1} dry weight has been derived. The current total concentrations in soil are generally < 0.5 mg/kg^{-1} dry weight, regardless of the soil type (sand, clay, peat) or land use (grassland, arable land, orchard, forest) and therefore lower than the MTC for inorganic mercury. Concentrations of approximately 1-10 mg/kg^{-1} dry weight have been measured in water meadows of the State waters and in polders raised with dredged harbour sediments, up to a factor of 10 higher than the MTC for inorganic mercury. In view of the toxicity data underlying the MTC, there is a risk that microbe-mediated processes are adversely affected at such mercury levels. Because of the lack of toxicity data, no statement can be made about effects on other soil organisms.

Mercury exists in soil mainly as inorganic mercury, but may also occur as elemental mercury and methylmercury. There are no data on the percentage of total mercury in each of these forms in Dutch soils. However, when "only" 5-10 per cent of the total amount of mercury is present as methylmercury, the MTC for methylmercury is exceeded in most soils and, considering the data underlying this MTC, there is a risk of biomagnification.

FEASIBILITY OF EMISSION REDUCTION OBJECTIVES

The general emission objective formulated for the priority substances calls for a reduction in the emissions by about 60 per cent in the year 2000 relative to 1985 (MV3 1993); the emissions to water should have been reduced by about 70 per cent and those to air by 50 per cent (SPEED 1993). A reduction in the emissions to (agricultural) soil, water and air of 50 per cent, 50 per cent and 80 per cent, respectively, is achievable by the year 2010. On the basis of two long-term scenarios (European Renaissance and Global Shift) presented in the National Environmental Survey 1993-2015 (MV3 1993), a reduction in the emissions to (agricultural) soil, water and air of 40 per cent, 70 per cent and 65 per cent is expected for the year 2000, while the objective is 80 per cent, 70 per cent and 50 per cent, respectively. It follows from this that the emission objective for air will be achieved. Regarding water there is uncertainty, due chiefly to the uncertain emission objective in the phosphorous fertilizer industry. The emission objective for (agricultural) soil, however, will not be achieved. This means that further accumulation of mercury in soil will occur. The rate of accumulation in the upper 30 cm of the soil is estimated to be about 0.2 $\mu g/kg^{-1}$ per year, roughly corresponding to an increase in concentration of about 0.1 per cent per year. The associated risks to man are limited. Although the relatively high mercury concentrations in shallow groundwater could entail a possible threat to the future drinking water supply, the concentrations (0.005-9.6 $\mu g/l^{-1}$) are relatively low compared to the total oral intake of mercury (about 0.4 $\mu g/kg^{-1}$ body weight). The risks to ecosystems (in the long term) are more difficult to asses. At present, there is insufficient insight into the chemical speciation of mercury in soil, the toxicity to soil-inhabiting animals, and the concentrations in soil-inhabiting animals in the mercury-contaminated areas and the resulting risks to predators.

With regard to the calculated increase in concentration of 0.1 per cent per year in the upper 30 cm of the soil, attention should be drawn to the environmental protection requirements as laid down in the Building Materials Decree (draft AMVB), in which the immission values of building materials are based on a soil mercury input resulting in a concentration increase of not more than 1 per cent of the desirable level (0.3 mg mercury/kg^{-1}) over a 100-year period (corresponding to 0.03 μg mercury/kg^{-1} per year) in 1 m^3 of standard soil which is to be regarded as homogeneous. The increase in the soil mercury content as a result of deposition is therefore about a factor of 2 higher than the maximum tolerable increase due to leaching from building materials.

MEASUREMENT STRATEGIES

The present integrated criteria document supports to a considerable degree the recommendations as set down in the Evaluation Report National Measurement Programme 1992. In this report, a distinction is made between exploratory measurement campaigns and regular measurement programmes, with the following being proposed:

Exploratory research

- In view of the occasional occurrence of high mercury concentrations in shallow groundwater, a study aimed at the establishment of a possible relation between acidification and high(er) mercury concentrations is proposed.

- Information on concentrations in fauna in the Netherlands is limited and relates exclusively to fauna in (relatively unpolluted) nature reserves. Further research is advisable in order to gain insight into these concentrations in mercury contaminated areas such as water meadows and polders raised with dredged harbour sediments, also for assessing the risk to top predators.

Multi-year programme

- Continuation of measurements on suspended and bottom sediments and in organisms (including fishery products) in fresh and salt surface water. At high concentrations, measurement of methylmercury is also advisable.

The Evaluation Report Mercury of the CCRX (Pieters et al. 1993) emphasizes the importance of measurements in fish and water birds.

Based on the available knowledge, it is recommended to pay attention especially to the concentration of methylmercury in shallow regional waters and in the various soils and soil-inhabiting animals, as part of the exploratory research.

CONCLUSIONS AND RECOMMENDATIONS

Environmental compartments

It is concluded that the emissions of mercury to the Dutch environment have fallen sharply in the past few years. With regard to the environmental compartments, the following conclusions can be drawn and recommendations made:

Soil and groundwater

In general, the mercury input to soil is determined to a considerable extent by atmospheric deposition. Although it is assumed that the deposition (due mainly to foreign sources) has decreased slightly, further accumulation of mercury will occur. This holds true to a greater extent for agricultural soil, where the input from the use of animal manure and chemical fertilizers in particular is not fully compensated for by removal by crop plants. Autonomous developments will result in a (further) emission reduction of up to 40-50 per cent (period 2000-2010), while the emission objective has been set at 80 per cent in order to prevent further accumulation of mercury in soil. In addition to a growing demand for measures on an international level, the question remains to be solved of how grave the risks associated with the mercury contamination of soil are. The risks to man are limited, but those to ecosystems (in the long term) are difficult to assess. For this purpose, further research into the concentration of methylmercury in soil, its toxicity to soil-inhabiting animals, and the concentrations in soil-inhabiting animals in mercury-contaminated areas, such as water meadows and harbour sediments raised polders, is advisable.

Surface water and sediments

The mercury concentrations in surface water have fallen sharply as a result of the reduction in emissions. The decrease in the mercury contamination of fish, too, can be partly attributed to this. The risk associated with the current concentrations in surface water is nil for man and, probably, only limited for aquatic ecosystems and animals preying on fish. Considering the expected further emission reductions, this risk will decrease further in the future to an acceptable level.

In sedimentation areas, many highly contaminated sediments have gradually been covered with newly supplied material having a lower mercury content. However, at locations where sedimentation does not occur the upper layer is heavily mercury contaminated. In terms of risks, the significance of this mercury load in the sediments is unclear. Most of the mercury in Dutch sediments is present as very stable HgS, and not bioavailable to most organisms. However, sulphate-reducing bacteria in sediments are capable of converting this form of mercury into methylmercury, which is readily taken up and only slowly excreted. At present, there is insufficient insight into the dynamics of this conversion process and the levels of methylmercury in the sediments of Dutch surface waters, particularly the shallower regional waters. Further research into this matter is advisable.

Air

The atmospheric mercury emissions in the Netherlands have fallen in the past few years, and will probably decline further to a level which surpasses the emission reduction objective. Present and thus certainly future airborne mercury concentrations do not entail risks to man or ecosystem; the atmospheric mercury contamination is only of significance in relation to deposition.

Amalgam

Based on recent literature studies, it has been concluded that there is insufficient evidence for the existence of a relation between the number of amalgam fillings and an increased prevalence of all kinds of complaints and symptoms. On the basis of indicative calculations, it can be computed that the maximum exposure via inhalation is at least a factor of 25 lower than the concentration at which, according to the WHO, effects can occur in sensitive individuals. Therefore, it is concluded that the risk associated with mercury from amalgam lies, in practice, within acceptable limits.

In case of policy arguments to reduce the existing risk further, the following facts should be considered.

Replacement of the current number of amalgam fillings (70-120 million in the Netherlands) has disadvantages. These disadvantages are not only of a financial nature (cost of replacement, cost of employing other material such as composite, gold or porcelain) or physical nature (discomfort for patients), but also concern public health aspects: the removal of amalgam is also accompanied by exposure to mercury. Although this exposure is of short(er) duration, the total exposure can be greater than that from not replacing the amalgam fillings. In addition, consideration should be given to the alternatives as filling, their dental aspects, costs, and risks to man and the environment.

Norway

Mercury has no known essential role in biological processes, but is one of the heavy metals that has the most severe effects on the environment and on human health. The risk reduction measures regarding mercury should therefore be based on a concern both for health and for the environment.

The ecotoxicological and toxicological properties of mercury make it one of the most hazardous substances released to the environment. Despite the great reductions in the amounts discharged per year, the mercury concentrations in the atmosphere and in the soil are increasing and mercury is still accumulating in the soil and aquatic compartments. In Norway increased concentrations of mercury are still measured in several fjords as well as in fresh water sediments. Therefore, restrictions on the consumption of some fish and shellfish species are still enforced in some areas.

The mercury released to the environment today, directly or indirectly, will bioaccumulate in the food chain and/or accumulate in the soil and in sediments. The cumulative effect may be both serious ecotoxicological and food-related problems.

Hence, it is of utmost importance to achieve the greatest possible reduction in the major sources of inputs of mercury to the environment.

Risk reduction on mercury is clearly an international issue. Mercury and mercury-containing products, as well as airborne or waterborne mercury as pollutant, will cross borders. International actions are therefore needed to reduce and solve today's and future problems of mercury pollution.

Mercury should be substituted wherever possible according to the technology available. It is most important to reduce/substitute the use of mercury for those applications that give rise to direct emissions/spreading and those that involve the greatest risk of hazardous effects. Research and development should be encouraged to find environmentally acceptable substitutes for areas of application where these alternatives do not exist today.

The aim should be to phase out the use of mercury.

Meanwhile, the amount of mercury released to the environment should be minimized, and highly effective recollection and recovery systems for mercury-containing products should be established.

Sweden

Mercury is extremely toxic, is readily taken up by organisms and tends to accumulate in the food chain. In Sweden, about 10,000 lakes are exceeding the national limit of 1 mg mercury/kg^{-1} in 1 kg pike. Fish from low productive lakes, even in remote areas, have been found to have high contents of mercury. Since the end of the 1960s, the emission of mercury in Sweden has been reduced dramatically. However, environmental concentrations are increasing. The general pattern of atmospheric deposition of mercury with decreasing values from the southwest part of the country towards the north, strongly suggests that the deposition over Sweden is dominated by sources in other European countries.

Mercury as an environmental pollutant is a global problem and thus an international approach is needed. The main strategy for risk reduction should be phasing out.

Most mercury-containing products can be substituted.

Products are an important source of environmental pollution. Mercury-containing products are long-lasting. There is, and has probably been for several centuries, an accumulation of mercury in society. When not separately discarded, the mercury will reach the environment through either waste incineration or long-term leakage from landfills. Therefore, it is important to plan for improved separate collection and for safe disposal of mercury and mercury-containing products. In the long run, a strategy built on recycling of mercury is not desirable.

There is an urgent need to phase out mercury and mercury compounds for all applications unless replacement products are not available according to the state of the art.

The Swedish Parliament has stated that the use of mercury in Sweden shall cease. The aim is to end the use of mercury in processes and products, with a few exemptions, until the year 2000.

United Kingdom

Introduction

Mercury is present in all parts of the environment. This is a consequence of emissions both from natural sources and from industrial use of mercury and its compounds. Industrial emissions may arise either from the intentional use of mercury in a particular process or from the burning of fossil fuels, metal processing and the use of fertilizers as a result of its occurrence as trace impurities in raw materials. The total quantity mobilised by human activities is smaller than that mobilized naturally, but emissions resulting from human activities may nevertheless be important because they may result in high local concentrations of mercury.

Mercury is a toxic substance having no known function in human biochemistry or physiology. It is desirable on health grounds that human exposure to mercury be kept as low as practicable. Where contamination by mercury exists or is likely to arise, action to reduce man-made contributions progressively should be taken as and when appropriate, taking account not only of the desirability of improving safety margins, but also of industrial economic viability, technical adequacy, and the availability of less hazardous substitutes.

Health Effects

Elemental mercury and inorganic mercury are poorly absorbed into body tissues, most being excreted shortly after ingestion. In contrast, the majority of methylmercury compounds ingested with food are absorbed but excreted only very slowly. Occupational exposure usually occurs via the lungs in the vapour phase and absorption through skin. Once absorbed into the body, all forms of mercury become widely distributed in tissues, the greatest accumulation occurring in the kidney and liver with adverse effects. Elemental and alkylmercury compounds also enter the brain and, if found in large enough quantities, can cause irreversible damage to the central system.

Exposure

Mercury can be taken up by plants and animals in freshwater, marine and terrestrial environments. Food is a major source of exposure to mercury for most people, i.e. those not occupationally exposed. In the UK the average dietary intake of mercury is falling. In 1987 the average dietary intake was 2-3 micrograms per day, of which 1 microgram may be in the form of methylmercury with the largest intake commonly derived from fish. Intake is therefore well below the FAO/WHO Expert Committee on Food Additives provisional tolerable weekly intake for mercury in the diet of 0.3 milligrams, of which not more than 0.2 milligrams should be organic mercury. This limit is respected by the UK Government and upheld by continued efforts to reduce the levels of discharges of mercury to the sea, as reflected in the target of a 70 per cent reduction for inputs by 1995 which was established at the Third North Sea Conference.

United States

United States agencies concerned with the health and environmental effects of mercury exposure, including the US Environmental Protection Agency, the Department of Health and Human Services, the Department of Transportation, and the Department of Labor, have drawn a number of conclusions regarding risks resulting from exposure to mercury.

Sources of Exposure (from ATSDR 1992b unless otherwise noted)

The major source of mercury exposure in the general population is through consumption of foods contaminated with mercury as a result of environmental releases of mercury and its subsequent accumulation in the food chain. Consumption of fish is the largest source of methylmercury exposure, while consumption of other foods is the primary source of exposure to inorganic forms of mercury. The largest anthropogenic contributors of mercury to the environment are coal-fired power plants, municipal waste combustors, and medical waste combustors. These sources release mercury to the air, with subsequent deposition to land and surface waters where transformation to methylmercury and bioaccumulation can occur. Methylmercury is found in almost all fish, with most species demonstrating levels around 0.1 to 0.2 ppm, and with several predatory species showing higher levels of 1 to 2 ppm.

Exposure to elemental mercury vapor can occur in certain occupational settings and in the general population through silver-mercury dental amalgams. A 1980 survey by the National Institute for Occupational Safety and Health (NIOSH) estimated that 70,000 workers, of whom about one-third were women, were potentially exposed to mercury vapor in the workplace (ATSDR 1992a). Most of these workers were employed as laboratory technicians, registered nurses, and machine operators, although workers employed in many other fields may be at risk of exposure. Mercury’s industrial uses are primarily in the production of chlorine and caustic soda, in ink manufacture, in electroplating operations, and in leather tanning and felt making. Mercury constitutes a significant weight fraction of silver dental amalgams. However, studies have not shown a clear and consistent relationship between the presence of amalgam fillings and blood levels of mercury. A recent report by the US Public Health Service (CCEHRP 1993) concludes that "current scientific evidence does not show that exposure to mercury from amalgam restorations poses a serious health risk in humans, except for an exceedingly small number of allergic reactions." However, the report cautions that there are significant gaps in the base of information relevant to assessment of chronic low-level mercury exposure. Mercury is also found in a variety of common household products including fluorescent lamps, batteries, electrical switches, and thermometers. Exposure to consumers is not expected to occur during normal use of these products.

Hazard Summary (from ATSDR 1992b, IRIS 1992, NTP 1993)

Most species of mercury are well-absorbed by their expected routes of exposure. Elemental mercury vapor is rapidly absorbed via inhalation; inorganic and organic mercury compounds are absorbed through ingestion and dermal exposure. The available evidence indicates that the metabolism and mechanisms of toxicity are similar for all species of mercury. However, some differences exist in the absorption and distribution of the various species because of differences in their respective physical and chemical properties. For example, elemental mercury vapor is absorbed especially quickly and accumulates in brain tissue to a greater extent than other mercury species. All forms of mercury can cross the placenta and exert their effects on the developing fetus.

The central nervous system (CNS) and kidneys are the key targets of mercury toxicity, with CNS effects apparently occurring at lower doses. A particularly severe manifestation of mercury poisoning is a syndrome known as acrodynia that occurs almost exclusively in children. Symptoms of acrodynia include apathy, anorexia, fever, kidney damage, and most characteristically, a painful blistering and peeling of the skin on the hands and feet.

EPA has established reference doses for certain mercury compounds. The Reference Dose (RfD) is an estimate of daily exposure to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime. An analogous estimate for inhalation exposures is called a Reference Concentration (RfC). The RfD for oral ingestion of methylmercury has been set at 0.0003 mg/kg/day based on CNS effects observed in human poisoning incidents. The RfD Work Group has recommended lowering the RfD for methylmercury to 0.00005 mg/kg/day based on observations of retarded mental development and paresthesia in children whose mothers were exposed to methylmercury during pregnancy. The RfD for phenylmercuric acetate is 0.00008 mg/kg/day based on kidney damage observed in a chronic dietary study in rats. An oral RfD and inhalation RfC on inorganic mercury are pending. A tentative RfC of 0.0003 mg/m^3 has been used by EPA Offices. EPA currently classifies inorganic mercury as a "Group D" carcinogen, "not classifiable as to human carcinogenicity" because of inadequate data. However, a 1993 National Toxicology Program Report concluded that there was "some evidence of carcinogenic activity" based on an increased incidence of forestomach tumors in male rats administered mercuric chloride by gavage.

Risk Reduction Activities

In order to help reduce environmental and occupational exposures to mercury, a number of US government agencies and industry groups have initiated regulatory activities and/or taken voluntary measures in an effort to promote public health.

Occupational Standards

The Occupational Safety and Health Administration (OSHA), part of the Department of Labor, has established a number of standards for industries using mercury. The OSHA standards set permissible exposure limits (PEL) on the concentration of mercury in workplace air over certain exposure intervals: an 8-hour time weighted average (TWA); a short term exposure limit (STEL), a maximum level for a 15-minute period; and a ceiling limit, a maximum concentration never to be exceeded in the workplace (OSHA 1989). The National Institute for Occupational Safety and Health (NIOSH) defines an additional limit called the IDLH (Immediately Dangerous to Life and Health) level, defined as the maximum environmental concentration of a contaminant from which one could escape within 30 minutes without any escape-impairing symptoms or irreversible health effects. NIOSH standards are not enforceable regulations but serve as guidance to OSHA and other regulatory bodies (NIOSH 1990). The American Conference of Governmental Industrial Hygienists (ACGIH), an independent association of professionals, has established an 8-hour TWA exposure limit called a Threshold Limit Value (TLV) (ACGIH 1990).

Transportation

The Department of Transportation (DOT), under the Hazardous Materials Transportation Act, designates mercury and its compounds as hazardous substances which are subject to requirements for packaging, shipping, and transportation (49 CFR 172.101, Appendix A).

Standards for Point Sources and Environmental Media

The Environmental Protection Agency (EPA) regulates mercury through actions taken in a number of its program offices. To protect the quality of the nation's surface waters, the EPA has developed guidelines, called Ambient Water Quality Criteria, that set acceptable concentrations of mercury in water for protection of human and aquatic life. These criteria are used to guide the development of specific effluent standards that regulate the release of mercury in effluent wastewaters from industrial facilities and municipal waste treatment plants. These controls are implemented through specifications in individual discharge permits under the National Pollutant Discharge Elimination System. EPA also regulates mercury as a Hazardous Air Pollutant under section 112 of the Clean Air Act, with National Emission Standards for certain industries. EPA's Office of Emergency and Remedial Response (OERR) has set rules for emergency planning at facilities where mercury is used or stored on site, and for mandatory reporting requirements when releases of mercury occur. EPA's Office of Solid Waste (OSW) classifies mercury as a hazardous substance, a designation that regulates the storage, transport, recycling and disposal of mercury wastes. In 1991, the EPA initiated the "33/50 Program", a special program to help reduce industrial releases of mercury and 16 other toxic substances into the environment. The goal of the program is to encourage companies to commit to voluntarily reduce their releases of some or all of these toxics by 33 per cent by 1992, and 50 per cent by 1995.

Drinking Water Standards

As part of its National Primary Drinking Water Standards required under the Safe Drinking Water Act of 1986, EPA has established a maximum contaminant level (MCL) for inorganic mercury in drinking water. The Food and Drug Administration has established a permissible level of mercury in bottled water (21 CFR 103.35).

Food Standards

The Food and Drug Administration (FDA) of the Department of Health and Human Services is responsible for regulating commercial fish and has established action levels for mercury in all edible seafood.

Pesticides

EPA, under the Federal Insecticide, Fungicide, and Rodenticide Act, has restricted the use of mercury-containing pesticides to a small number of specific applications. The use of mercury preservatives or antimicrobials in cosmetics has been limited by the FDA, in both its application and acceptable concentrations.

Drugs and Medical Devices

FDA regulates the safety of mercury-containing substances that are used in "Over-the-Counter" (OTC) drugs such as anorectal products, vaginal contraceptives, and topical antiseptics. FDA also regulates dental mercury and amalgam alloys.

Other Products

Consumer products containing mercury that end up in municipal waste have raised significant concerns with local, state, and federal authorities. Manufacturers of products such as batteries, fluorescent lamps, coated papers, and fever thermometers have taken steps to reduce or eliminate mercury in these products. EPA in January 1993 proposed a regulation that would allow states, manufacturers and others to set up special collection programs to facilitate the recycling and proper management of certain hazardous consumer wastes.

CHAPTER 5

MECHANISMS FOR RISK REDUCTION

Many OECD Member countries have taken steps to reduce risks from mercury. Requests for information on mercury risk reduction activities were made to all Member countries in 1993-94. The national viewpoints presented in this chapter are mainly based on the responses to these requests.

Responses were received from the majority of Member countries. Also included in this chapter are statements on risk reduction initiatives from the European battery and chlor-alkili industries.

The information provided by Member countries is summarized in the tables in **Annex A** to this chapter.

Australia

Releases to air, water and soil are controlled by a variety of legislation or regulation. Sources controlled include:

- energy production with burning of coal
- refuse incineration
- metal mining and production
- gold mining
- chlor-alkali industry
- dental clinics
- crematoria
- other emissions.

At present different regulations exist in the different states concerning mercury in batteries.

No detailed information was received concerning legislation for use of mercury in products.

There is limited use of mercury in paint manufacture, but exact figures are not available.

The phase-out of mercurial fungicide sprays from turf applications will be complete by the end of 1996, with sales to terminate by the end of 1994. Methoxyethylmercuric salts are still used as a pre-plant dip on sugar cane setts, on average once every seven years. Ongoing monitoring of canefield soils indicates slight increases in mercury concentrations, but not beyond levels found in nature (see Appendix 6). It is anticipated that this use will be withdrawn as soon as a suitable alternative is found.

Austria

The following detailed information has been received:

The use of mercury in antifouling paints was banned in 1990.

There has been a deposit on fluorescent lamps since 1991.

Batteries which contain more than 0.001 per cent mercury are prohibited; retailers have to take back used batteries and accumulators for controlled disposal.

Mercury in plant protection products and seed dressing is prohibited.

Air pollution through boiler plants (waste incineration) must not exceed 0.1 mg/m^3 in small and medium-sized plants and 0.05 mg/m^3 in big plants.

Mercury-containing waste has to be treated as hazardous waste.

A quality standard exists for dental amalgams, which have to be labelled properly. In addition, dentists have to install amalgam separators with a separation efficiency of at least 95 per cent.

The mercury limit for wastewater emissions to river or sewer and leachate emissions is 0.01 mg/litre.

Groundwater must not contain more than 0.001 mg mercury/litre.

Mercury limits for drinking water are 0.001 mg/litre.

Limits for sewage sludge exist.

Quality standards for food range between 0.01 and 1.0 mg/kg.

The occupational health standard is 0.005 ppm.

Belgium

Only the following detailed information concerning regulations for water has been provided:

- Base quality for normal surface water: 0.5 µg/litre.
- Emissions to surface waters (wastewater): max. 0.15 mg/litre.
- Monthly: max. 0.1 g/tonne chlorine produced.
- Chemical plants using mercury catalyst for production of other than vinylchloride: monthly: max. 5 g/kg used mercury.
- Fabrication of organic and non-organic mercury compounds; non-ferro and treatment of mercury-containing toxic waste: monthly: max. 0.05 g/kg mercury utilized.
- Fabrication of primary batteries: monthly: max. 0.03 g/kg mercury utilized.
- Textiles: max. 0.02 mg/litre.
- Cleaning of vessels: max. 0.01 mg/litre.
- Pigments, paints, inks; cleaning of ships and cars transporting fluids: max. 0.001 mg/litre.
- Pulp and paper industry: 0.

Use of mercury in paints has been forbidden since 1991, and use of mercury in seed dressing since 1990.

Use of mercury-containing batteries is regulated by the EU as described in the **European Union** section of this chapter.

Table 5.1 Sectorial Norms for Mercury in Industrial Wastewater Discharges in Belgium

Activity or sector	Mercury	
	Surface water	Sewer
Chlorine production		
pickle: daily average per tonne of chlorine capacity	0.5 g mercury	discharge prohibited
total discharge: month	0.05	
· day	0.2	
· max 1 day/month	2	
new plants: discharge of lost pickle prohibited	0	
Chlorinated hydrocarbons, derivates and polymers (pesticides excluded)		
solvents: specific discharge volume	100 m^3/kg mercury	
· total mercury	0.15	
· total mercury: day	10 g/kg	
· total mercury: month	5 g/kg	
VCM: specific discharge volume	2 m^3/tonne	
· total mercury	0.15	
· total mercury: day	0.2 g/tonne cap.	
· total mercury: month	0.1 g/tonne	
Pharmaceutical industry		
pure chemical: total mercury	0.15	
· total mercury: day	0.2 g/kg	0.1 g/kg
· total mercury: month	0.1 g/kg	0.05 g/kg
semi-synthesis and fermentation: total mercury	0.15	
· total mercury: day	0.1 g/kg	
· total mercury: month	0.05 g/kg	
laboratories: total mercury	0.15	
· total mercury: day	0.1 g/kg	
· total mercury: month	0.05 g/kg	
Laboratories	0.01	
Varnishes, paints, inks and pigments		
· total	0.001	0.1
Non-ferrous metals		
· total	0.15	
· day	0.1	
· month	0.05	
Paper, board and pulp	<DL	
Cleaning of cars and ships transporting fluids	0.001	0.005
Dumps	0.15	
Textile processing (ennoblement)	0.02	
Cleaning of vessels	0.01	

Remark: when not mentioned, unit is mg mercury/litre

Canada

Canada has federal legislation, regulations and guidelines relevant to the control or reduction of mercury in air, water, waste effluents, marine disposal, contaminated sites, consumer products, pest control products and for occupational exposure. A document entitled *Regulatory Framework for Risk Management of Mercury in Canada* is available.

Federal regulations which set criteria for air emissions from chlor-alkali factories are specified in Annex 6 of this document. The maximum amount of mercury that may be deposited in liquid effluent from chlor-alkali plants is 0.0025 kg mercury per ton of chlorine produced (see Annex 6).

The recommended maximum concentration of mercury dissolved in effluent wastes is 0.001 mg/litre (National Guidelines on Physical-Chemical-Biological Treatment of Hazardous Waste). The Special Waste Management Regulations in the province of British Columbia specify maximum mercury emission criteria of 0.2mg/m^3 for hazardous waste incinerators. Recommendations for stack discharge limits and anticipated emissions for mercury are made in the Operating and Emission Guidelines for Municipal Solid Waste Incinerators published by the Canadian Council of Ministers of the Environment (CCME). Provinces use these guidelines when issuing permits to facilities under their respective jurisdiction. Mercury emissions of up to 0.2 mg/m^3 are anticipated from municipal solid waste incinerators operating under good combustion conditions and equipped with dry scrubber fabric filter systems.

Interim criteria for the assessment and remediation of water and soil have been published by CCME (Interim Canadian Environmental Quality Criteria for Contaminated Sites, see Annex 5). It should be noted that these criteria are to be subjected to a validation protocol currently being finalised within CCME.

Centralised composting sites are becoming increasingly widespread as a result of recycling activities. The number of centralised composting facilities, private and municipal, throughout Canada has more than tripled, from 30 sites in 1989 to over 120 sites in 1994. The amount of mercury allowed in compost is regulated under the Fertilizers Act, administered by Agriculture Canada, at a maximum concentration of 5 mg/kg. The CCME is presently working on new national guidelines for compost. Their proposal is a maximum mercury concentration of 0.8 mg/kg or 5 mg/kg depending on the use (unrestricted or restricted).

In Canada, disposal at sea is only permitted for non-hazardous substances and where it is the environmentally preferable and practical alternative. Permits are not granted if practical opportunities are available to recycle, reuse or treat waste. Canada controls disposal at sea and meets its international obligations under the London Convention (1972) by means of a permit system in place since 1975. The CECA is the enabling legislation for the permit system and includes provisions for making regulations. Under the Ocean Dumping Regulations (1988), materials containing mercury can be authorised for ocean disposal only if mercury occurs at or below the regulated levels (i.e. in the solid phase of a waste, 0.75 mg/kg, and in the liquid phase of a waste, 1.5 mg/kg). Applications for disposal of dredged or excavation material must include concentrations of mercury in the material proposed for sea disposal. In keeping with decisions made at the London Convention 1972, Canada is in the process of amending the regulations to prohibit sea disposal of industrial wastes.

It is prohibited to sell, advertise or import into Canada toys, equipment and other products for use by a child in learning or play that have applied to them a decorative or protective coating that contains any compound of mercury introduced as such (Hazardous Products Act). Formulations containing mercury as an active ingredient are approved as material preservatives for commercial products, primarily wood, under the Pest Control Products Act. No registered pesticide with mercurial compounds is allowed as a fungicide treatment in seed dressing.

The Domestic Substances List, established under CEPA, identified 32 mercury compounds in commerce in Canada. Mercury compounds not on this list are deemed to be new to Canadian commerce, and their introduction requires notification according to the New Substances Notification Regulations under CEPA.

Canada has Environmental Choice Guidelines concerning mercury in batteries as specified in Annex 1, with elimination of mercury in batteries to be achieved between 1994 and 1996. A voluntary removal of mercurial compounds in interior latex paint has been done by the major Canadian paint manufacturers, but this does not apply to exterior paints. The Canadian Paints and Coatings Association has a recycling programme for waste household paint and containers with limited mercury content.

Occupational exposure limits for mercury are equivalent to the values published by the American Conference of Government and Industrial Hygienists (ACGIH) in "Threshold Limit Value and Biological Exposure Indices" (Canada Labour Code). The presence of mercury in workplace substances must be disclosed on material data safety sheets (Ingredient Disclosure List).

Guidelines for food safety, based on technical reports from annual meetings of the joint FAO/WHO Expert Committee on Food Additives, recommend that the total concentration of mercury in the edible portion of fish must not exceed 0.5 ppm on a wet weight basis. Swordfish and shark are exempted; however, consumption of these species should not exceed one meal per week.

Canada has established national and regional data bases which identify elevated levels of metals in various media. For example, the National Geochemical Reconnaissance data base contains sediment and/or soil data for an area 2.1×10^6 km^2, 80 per cent of which contains mercury data. There are also numerous provincial initiatives such as large data bases for mercury in fish and baseline geochemistry programmes.

Denmark

Present regulation

Industrial use and emission of mercury is regulated by the Environmental Protection Act.

The mercury content in sewage sludge for agricultural purposes is limited, and from 1995 will be further limited.

Mercury-containing waste has to be treated as hazardous waste.

Future regulation

To minimize use, the existing regulation is not sufficient. Alternative substances to mercury and processes not involving mercury have to be used. Fortunately, alternatives exist for all major uses.

The implementation of this policy is done by banning the use of mercury for products and processes where alternatives exist. A draft regulation has been issued which meets this objective. The content of the draft regulation is:

- The general rule is that sale of mercury and mercury-containing products is prohibited from 1 July 1994.

- From this general rule derogations are made for those special areas, where alternatives are not available at present. Thermometers containing mercury (except for very special uses, which are listed) are prohibited at once. Dental fillings containing mercury (except for molar teeth, where the date is 1999) is prohibited in 1995. Derogations until further notice are also made for special listed uses of light sources, contacts, pressure gauges, barometers, electrodes and chemicals. Finally, use is permitted until further notice for research, education, vital applications in aircrafts, repair of existing mercury-containing equipment, and as a natural pollution in coal. For batteries and electrolysis, special rules apply.

(Also see the section on the **Nordic countries** in this chapter.)

Finland

Emissions to air, water and soil are regulated by the Air Pollution Control Act, the Water Act and the Waste Act. Emission limits are set on a case-by-case basis during the environmental permit procedure. Finland has also implemented the EEC Directives for the chlor-alkali industries (82/176/EEC) and other sectors (84/156/EEC) as well as for municipal waste incineration plants (89/369/EEC and 89/429/EEC). These Directives include emission limits.

Use of mercury for seed dressing has been forbidden since October 1992.

There is no general ban or restriction on the use of mercury in paints. The use of mercury in antifouling paints was banned in 1992.

Regulations concerning the use, delivery, labelling and collection of mercury-containing batteries are under preparation. These regulations, enforced in Finland, will be the EEC Directives 91/157/EEC and 93/86/EEC on batteries.

According to the Council of State Decision (282/94), sludge or a sludge mixture for agricultural use may contain maximum 2 mg mercury/kg dry weight.

Finland has approved the 1988 Declaration on the Protection of the Marine Environment of the Baltic Sea Area, of the Helsinki Commission (HELCOM), setting the goal of a 50 per cent decrease in discharges and emissions by 1995.

The quality standard for drinking water, established by the Ministry of Social Affairs and Health, is 1 µg mercury/litre.

According to a recommendation of the National Board of Health, fish that contains 0.5-1 mg of mercury/kg should not be eaten more than once a week, and fish containing more than 1 mg of mercury/kg should not be used at all in the human diet.

The Ministry of Social Affairs and Health has recommended that the use of amalgams in dental fillings should cease by year 2000.

(Also see the section on the **Nordic countries** in this chapter.)

France

Control of emissions to air, water and soil are regulated by different EEC Directives, as described in the **European Union** subchapter.

A French order prohibits the incineration of waste containing mercury.

Use of mercury-containing batteries, paint and seed dressing is also regulated by the EU and described in the European Union subchapter.

In the future, emissions of mercury to air, water and soil will be regulated in accordance with EEC, Paris Commission and the International Commission for Protection of the Rhine requirements.

The future strategy for use of mercury in products is pending, while waiting for further information in relation to:

- risk evaluation for man and environment
- efficacy
- economic feasibility

concerning the products or methods for substitution.

Germany

Control of emissions to air, water and soil is regulated by national legislation based on the different EEC Directives described in the **European Union** subchapter.

Administrative rules on the quality standards of wastewater from dental treatment imply that the mercury load of raw wastewater from dental treatment must be reduced by 95 per cent before mixing with domestic sewage. This can be ensured by utilisation of amalgam separators with a separation capacity of a least 95 per cent.

Sewage sludge may only be used as manure on soils which contain not more than 1 mg mercury/kg air-dried soil. In addition, the mercury concentration in the sludge must not exceed 8 mg mercury/kg dried sludge.

Mercury compounds or preparations containing mercury compounds must not be used or marketed for the following purposes: as antifouling, for the protection of wood, for the impregnation of heavy industrial textiles, and for the production of yarns for heavy industrial textiles, and for water processing in industrial, business and municipal sectors independent of its use.

Since 1983, paints may not be provided with mercury preparations as antifouling compounds. Since 1982, pesticides consisting of or containing mercury compounds may not be used.

It is planned that the chlor-alkali industry shall phase out the use of mercury before 2010.

An ordinance was presented to the government on 8 July 1992 with the following main purposes:

- A ban on alkaline-manganese batteries with more than 0.025 per cent mercury from 1 January 1993. For special applications, i.e. at extreme temperatures, batteries up to 0.05 per cent mercury are allowed.

- An obligation to label batteries containing more 0.025 per cent mercury or more than 25 mg mercury/battery cell.

- To ensure that batteries are collected separately and raise the recycling rate of batteries.

Restrictions on the use of mercury in thermometers, contacts and similar instruments are under discussion.

Ireland

Control of emissions to air, water and soil are regulated by different EEC Directives, as are mercury-containing batteries, paint and seed dressing. All are described in the **European Union** subchapter.

Japan

Different environmental legislation/regulation controls emissions to air, water and soil.

Refuse incineration is regulated concerning releases to soil, and by a waste disposal and public cleaning act.

Regulations exist for metal mining and production, which control emissions to water and soil.

Other emissions are controlled by the Water Pollution Control Act, which sets the following effluent standards:

- total mercury	0.005 mg/litre
- alkyl mercury compounds	not detectable

The purpose of the law is to prevent the pollution of public water areas and groundwater, and thereby to protect human health and to conserve the living environment, by controlling effluents from factories and establishment into the public water areas and permeations into underground. It further aims at promoting countermeasures for household wastewater, and to protect the sufferers by deciding the liability of the proprietor of the factories and establishment to compensate for any damage.

Japan has established Environmental Quality Standards (EQS) for Water and Effluent Standards concerning mercury and has carried out various water protection measures. As a consequence, there are very few cases where mercury levels higher than EQS have been measured in public water areas.

Household paint must not contain organomercury compounds; this has been regulated since 1973/74.

No pesticide containing mercury, including pesticide for seed dressing, has been registered since 1973.

Based on the Industrial Safety and Health Law, employers should take measures to decrease the mercury level at a workplace and/or to keep workers from inhaling mercury.

In 1984, the chlor-alkali industry stopped using mercury. As a consequence, the total amount of mercury used in Japan was reduced to 212 tonnes. 122 tonnes, more than 50 per cent, was used for dry batteries.

A great deal of effort has been made to reduce the amount of mercury used for dry batteries. In 1992, no mercury addition version was achieved for both zinc-carbon battery and alkaline manganese batteries for general purpose applications. As a consequence, the total amount of mercury used for dry batteries was reduced to be 42 tonnes. Almost all of this amount was used for button cell batteries, mainly of the mercuric oxide type.

Eighty per cent of mercuric oxide batteries were used for hearing aid applications. As a result of extensive publicity and discussions with general consumers, the mercuric oxide batteries for hearing aid application were replaced by zinc air batteries, and consequently, production of mercuric oxide batteries for hearing aid application was stopped in 1994. The amount of mercury used for dry batteries will, therefore, decrease to less than 10 tonnes.

In addition, production of mercuric oxide batteries is scheduled to stop completely by the end of 1995.

The Netherlands

Present regulation

- Control of the emissions to air, water and soil are regulated by national legislation based on the different EEC Directives described in the **European Union** subchapter.

- A licence is obligatory for the drainage of mercury to surface water.

- Limits for mercury in surface water, drinking water, groundwater, soil, sewage sludge, organic fertilizers and air.

- Maximal content of mercury in batteries. Implementation of the EC Directive 91/157/EEC.

- Ban on the use of shock absorbers for arms and legs containing mercury.

- Convention between the national organisation of dental surgery and the public authorities to collect amalgam separately with at least a 95 per cent profit.

- The use of pesticides containing mercury is not permitted.

Future regulation

In first instance, priority is given to minimizing, and where possible to replacing, the use of mercury in the following products:

- the use of amalgam by dentists,
- thermometers and other measuring instruments,
- batteries,
- switches,
- lighting (vapour discharge lamps).

These products contribute to the greater part of the use of mercury in products.

In recent research, all mercury-containing products in the Netherlands and the availability of alternatives were investigated. It is expected that, for some products, a longer time will be needed before the use of mercury could be phased out, because no alternatives of the same value are yet available.

Norway

No specific regulations have been developed which restrict the industrial use and emissions of mercury. Specific permits are set in the discharge permits for each industrial and waste incineration plant, pursuant to the general legislation on environmental protection (the Pollution Control Act).

For the chlor-alkali industry, the limit value for discharges to water is 0.25 g mercury/tonne chlorine capacity, and for emissions to air 2.5 g mercury/tonne of chlorine. The mercury-based process will be replaced with a mercury-free process by 1998.

Regulations restricting discharges from dental clinics have been proposed. Installation of mercury separators and separate collection of mercury-containing waste will be required. Mercury-containing waste has to be treated as hazardous waste.

Mercury has not been used in paint since 1970, owing to internal agreement among paint producers.

It is prohibited to manufacture, export, import or sell zinc/carbon and non-rechargeable alkaline manganese batteries which contain 0.001 per cent or more mercury by weight. After 1 January 1995, the ban will include all types of batteries (even button cells). Packaging containing individual button cell batteries of the type mercury oxide, silver oxide, zinc/air or other types containing a total of 0.025 per cent mercury shall be labelled with a recycling symbol. Retailers who sell batteries that shall be marked/labelled, are obliged to accept comparable types of batteries for appropriate disposal from the consumer, free of charge.

Norway has banned the use of mercury for seed dressing since 1 December 1991.

A ban on the production, import and sale of mercury-containing thermometers has been notified.

It is the future strategy of the government to obtain further reduction in emissions of mercury.

(Also see the section on the **Nordic countries** in this chapter.)

Sweden

In 1991, the Parliament stated that the use of mercury in Sweden shall cease. In 1994, a general goal for ending the use of mercury in most processes and products was set till the year 2000. The Parliament also stated that the use of mercury in dental amalgams should have come to an end in 1997.

Several projects are planned at the Swedish environmental agencies in order to fulfil parliamentary purposes. This includes measures concerning the disposal of products containing mercury, as well as a plan to gradually set the use of dental mercury amalgams.

The following is a brief presentation of Swedish regulations on mercury:

The Act (1969:387) on Environmental Protection is applied for regulation and control of industrial emissions of mercury.

Sweden has a programme for site remediation, including an inventory of different sites where industrial and other polluting activities have taken place. The chlor-alkali industry is one of those being investigated.

Guidelines on mercury emissions from dental amalgams are set up. There is also an agreement on installation of mercury separators at dental clinics.

Mercury-containing waste is treated as environmentally hazardous waste (Ordinance 1985:841) and is to be handled separately.

It is prohibited to transfer or to offer sewage sludge containing more than 2.5 mg mercury/kg dry weight for sale for agriculture purposes (Ordinance 1985:840, amendment 1993:1271).

Import, sale, transfer and use of mercury and mercury compounds as biocides are regulated in the Ordinance (1985:836) on Pesticides. No mercury-containing product is approved.

The use of mercury-containing seed dressing is banned (Ordinance 1979:349).

It is prohibited, in the course of business activities, to transfer alkaline batteries containing more than 0.025 per cent mercury and cadmium by weight. Button cell batteries and batteries composed of button cells are exempted. Batteries containing mercury and/or cadmium shall be labelled and delivered for separate treatment. There are special fees for the transfer of environmentally hazardous batteries (Ordinance 1989:974).

Finally, there is a prohibition on certain products containing mercury (Ordinance 1991:1290). From 1 January 1992, clinical mercury in glass thermometers is prohibited for import, manufacture in the course of business activities, and sale. The same applies to other types of thermometers, measuring instruments and apparatus and electrical components containing mercury from 1 January 1993.

Due to actions taken by Swedish industry, the use of mercury in products not mentioned in the prohibition is also ceasing.

Experience to date shows that all mercury thermometers, most measuring instruments and most electrical components have satisfactory alternatives for different measuring situations and for most equipment. Temporary exemptions have been granted to make it possible for some users to successively convert to other techniques. The main policy is to exempt products where sufficient alternatives are not available, or where research and development are required to develop alternatives. Special attention is paid to safety demands.

A presentation of alternatives is given below.

Prohibited products containing mercury and their alternatives

Thermometers and other measuring instruments

For a comparable price, there are several reliable alternatives to clinical mercury in glass thermometers. There are both electric and single-use alternatives.

Mercury in glass thermometers within the measuring area -38°C to +200°C could be replaced by thermometers with other liquids such as butyl alcohol, hexanol or xylene. The price is about the same. This mercury can also be replaced by electric and electronic instruments.

For applications of up to 700°C, a Pt-100, also called a Resistant Thermo Device (RTD), can be used. Within the measuring area 400°C to 1500°C, different thermocouples can be used.

When measuring below -38°C and above +650°C, it is not possible to use mercury.

Electrical components

With a few exceptions, there are no technical obstacles to replacing components containing mercury such as level switchers, thermostats, relays and electrical contacts. Conventional relays and other contacts with mercury, also when these are contained in switchers and thermostats, can normally be replaced by a mercury-free component. This is not only applicable when fitting components into equipment being manufactured, but also when exchanging spare parts in older equipment.

Most mercury contacts can be replaced by, for example, solid-state contacts. Several types of tilt switches and most level switches can be substituted. The use of conventional mercury relays has ceased, and the more technically developed mercury wetted relays have become more common. For some applications it is possible to use semi-conductors or solid-state relays instead. What seems most complicated is to substitute tilt switches when there is no fixed reference point, for example in personal alarm systems.

(Also see the section on the **Nordic countries** in this chapter.)

Switzerland

In 1986, a regulation was established concerning a gradual decrease in mercury in alkaline and manganese batteries. These regulations are presently under revision.

Since 1986 a ban has existed on the use of mercury in all products. A list of exemptions is given, along with a gradual reduction of mercury in the products according to technical possibilities.

Use of mercury in paint has been forbidden for several years, and use of mercury as seed dressing has been forbidden since 1991.

Limits for emissions to air were established in the Clean Air Ordinance in 1985:

Emission limits for installations: 0.2 mg/m^3 if the mass flow is 1 g/h or more. Emission limit for waste incineration is 0.1 mg/m^3.

Limits for emissions to water were established in the Ordinance for Waste Water Discharge in 1975:

Water quality criteria for surface water flows and impounded river water: 0.001 mg mercury/litre; quality standard for effluents discharged into surface waters: 0.01 mg mercury/litre; quality standard for effluents discharged into public sewers: 0.01 mg mercury/litre.

Limits for emissions from dental clinics (1988): Since 1993, dental clinics involved in amalgam treatment have to be equipped with an amalgam separator with at least 95 per cent separation rate.

The Ordinance on Contaminants in Soil (1986) indicates 0.8 mg/kg as a guide value for the total content of mercury in soil.

According to an amendment (1992) to the Ordinance on Substances (1986), the mercury content shall not exceed a maximum level of 1 mg/kg in compost and 5 mg/kg in sewage sludge.

Limits for emissions from the chlor-alkali industry are regulated in accordance with the recommendation of the International Commission for the Protection of the Rhine against Pollution, dated 28 June 1979. Since 1983 the water emission limit is 0.5 g/tonne chlorine capacity.

In accordance with the recommendation of the International Conference on the Protection of the North Sea of 8 March 1990 (annex 1B), mercury cell plants shall be phased out by 2010 and the air emission limit shall be 2 g/tonne chlorine capacity by 1996.

United Kingdom

Control of emissions to air, water and soil are regulated by different EEC Directives, as are mercury-containing batteries, paint and seed dressing. These are described in the **European Union** subchapter.

There is no specific legislation controlling the supply of other mercury-containing products.

The future general strategy for mercury is to minimize the amounts of mercury which can reach the environment from man's activities, including the use of mercury-containing products.

A reduction target for emissions to water from land-based sources was confirmed and extended at the third ministerial conference on the North Sea in 1990. The target requires inputs of mercury to the North Sea to be reduced by 70 per cent, using 1985 inputs as the baseline. This target will be applied to all coastal waters including the North Sea.

United States

The United States has been actively addressing the risks posed by exposure to mercury for many years. Current regulatory activities undertaken by many different government agencies are successfully helping to reduce potential human exposures to mercury by controlling its releases into the environment and limiting or discontinuing uses that result in high exposures. The US government also supports a variety of research efforts that will help to better evaluate the impacts of our industrial activity and improve the understanding of mercury's toxicity. The information discussed in this chapter is summarized in the table, "United States Risk Reduction Efforts for Mercury", at the end of **Annex A**.

Mercury in Drinking Water

The Environmental Protection Agency's Office of Ground Water and Drinking Water (OGWDW), as part of its National Primary Drinking Water Standards required under the Safe Drinking Water Act of 1986, established a maximum contaminant level (MCL) for inorganic mercury in drinking water of 0.002 mg/litre (effective July 30, 1992) (40 CFR 141.62). The permissible level of mercury in bottled water, set by the US Food and Drug Administration, is also 0.002 mg/litre (21 CFR 103.35).

Standards for Mercury in Environmental Media and Point Source Controls

The Environmental Protection Agency (EPA) regulates the release of mercury into environmental media (i.e. air, water, and soil) through actions taken in a number of its program offices. The Office of Science and Technology (OST) within the Office of Water controls the release of mercury in effluent wastewaters from industrial facilities and municipal wastewater treatment facilities under the general pretreatment standards and effluent guidelines for existing and new sources of pollution (40 CFR 401, and 403, Appendix B). Implementation of these limits is accomplished through individual discharge permits under the OST's National Pollutant Discharge Elimination System. EPA's Office of Water has set additional guidelines, called Ambient Water Quality Criteria, that recommend acceptable concentrations of mercury for the protection of human health and aquatic species (EPA 1986). The criteria are as follows:

Human health: 1.44×10^{-4} mg/litre for ingesting both water and aquatic organisms
1.46×10^{-4} mg/litre for ingesting aquatic organisms only

Aquatic life: 2.4×10^{-3} mg/litre for freshwater acute exposures
1.2×10^{-5} mg/litre for freshwater chronic exposures
2.1×10^{-3} mg/litre for marine acute exposures
2.5×10^{-5} mg/litre for marine chronic exposures

The mercury content of municipal wastewater treatment sludges intended for land application or surface disposal is regulated by the EPA under the Clean Water Act. The mercury concentration of sludge that will be applied to agricultural land, forest land, or other public contact sites may not exceed 17 mg/kg (dry wt) and the cumulative loading of mercury may not exceed 17 kg/hectare. Sludge sold or distributed for application to a lawn or home garden is also limited to 17 mg/kg (dry wt) of mercury and may not exceed an annual mercury loading rate of 0.85 kg/hectare. Sludge sold or distributed for other types of land application may not exceed a mercury concentration of 57 mg/kg (dry wt). Sludge intended for surface disposal at either lined or unlined facilities may not contain more than 100 g/kg (dry wt) of mercury (EPA 1993a).

EPA regulates mercury as a Hazardous Air Pollutant (40 CFR 61.01) and has established National Emission Standards for several major point source categories of mercury. The emission standards are designed to prevent monthly average mercury concentrations from exceeding 1.0 $\mu g/m^3$. Emissions from mercury ore processing facilities and mercury cell chlor-alkali plants are limited to a maximum of 2300 grams of mercury per 24 hours. Emissions from sludge incineration plants, sludge drying plants, or a combination of these that process wastewater treatment plant sludges are limited to a maximum of 3200 grams of mercury per 24 hours (40 CFR 61.52). The Clean Air Act Amendments of 1990 contain a number of provisions relating to additional study and regulation of mercury:

- A required study of the health and environmental risks, control technologies, and costs of control for all mercury sources, including electric utilities and municipal waste combustors. Results of the study, due by November, 1994, will be used to guide the development of additional emission standards for mercury (CAAA 1990).

- Identification and regulation of the 30 most significant Hazardous Air Pollutants from urban "area sources" (small, numerous sources); mercury is very likely to be among the 30 priority chemicals.

- Hazardous Air Pollutant provisions require that regulations controlling both "major sources" and "area sources" account for at least 90 per cent of total emissions.

- A study of health and environmental impacts of atmospheric deposition to the Great Lakes, Chesapeake Bay, Lake Champlain, and coastal waters; report due November, 1993; regulation as necessary due November, 1995; mercury has been identified as a high priority for this study.

- New Source Performance Standard for Municipal Waste Combustors – will establish numerical emission limits for new combustors.

- Updated standards for chlor-alkali plants – primarily directed at chlorine emissions but may affect mercury emissions as well.

The Office of Emergency and Remedial Response (OERR), under the statutory authority of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the Emergency Planning and Community Right to Know Act (EPCRA), has established mandatory reporting requirements for significant releases of mercury and has set rules for emergency planning at facilities where mercury is used or stored on site. The limits that trigger reporting and emergency planning requirements are defined by Reportable Quantities (RQs) and Threshold Planning Quantities (TPQs), respectively (40 CFR 302.4; 40 CFR 355 Appendix A). RQs and TPQs for mercury and 14 of its compounds are listed in the table, "United States Risk Reduction Efforts for Mercury", at the end of Annex A.

The potential release of mercury from transportation accidents is reduced through the Department of Transportation's Hazardous Materials Transportation Act, which designates mercury and its compounds as hazardous substances and subjects them to requirements for packaging, shipping, and transportation (49 CFR 172.101, Appendix A).

The EPA's Office of Solid Waste (OSW), responsible for implementing the Resource Conservation and Recovery Act (RCRA), has also designated mercury a hazardous substance and requires that groundwater at hazardous waste treatment, storage, and disposal facilities be monitored for its presence (40 CFR 302.4 and 264.94). RCRA's Land Disposal Restrictions further restrict the disposal of mercury-containing wastes in Subtitle C (Hazardous Waste) land disposal facilities. Depending on the amount of mercury in the waste, mercury wastes must undergo either a prescribed treatment technology (roasting/retorting) or meet a treatment standard of 0.20 mg/litre in the extract obtained from Toxicity Characteristic Leaching Procedure (40 CFR 268).

Industrial Source Reduction

In 1991, the EPA initiated the "33/50 Program", a special program to help reduce releases of mercury and 16 other toxic substances into the environment. The goal of the program is to encourage companies to commit to voluntarily reduce their releases of some or all of these toxics by 33 per cent by 1992, and 50 per cent by 1995. The program takes advantage of a large EPA database that maintains information on industrial releases of toxics (the Toxics Release Inventory or TRI) to help persuade industries to reduce releases of toxic substances. The 33/50 Program reports that between 1988 and 1991 environmental releases of mercury from TRI facilities were reduced by 38 per cent and that transfers of mercury for off-site treatment or disposal were reduced by 30 per cent (EPA 1993b).

Mercury in Foods

The major source of methylmercury exposure is fish consumption. The mercury concentration in fish at the top of the food chain can be biomagnified up to 100,000 times the concentration in surrounding waters (ATSDR 1992a). In an effort to reduce methylmercury exposure from fishery products, the US Food and Drug Administration (FDA) has established an action level for methylmercury. The action level is 1 ppm for methylmercury in the edible portions of fish, shellfish, and other aquatic animals, whether fresh, frozen, or processed (FDA CPG 7180.07). The action level is intended to eliminate from consumption those fish and fishery products whose methylmercury levels exceed the action level. Some states, however, have adopted advisory levels for sport fish that are even more stringent than the FDA action level because they are concerned with specific populations whose fish consumption may be higher than that of the general population. The FDA action level is designed to address consumption by the general population.

Mercury exposure can also occur through the consumption of foods prepared from crops that have been treated with mercury-containing pesticides. During the winter of 1971-72, thousands of Iraqis were poisoned by eating homemade breads made from seed wheat that had been treated with a methylmercury fungicide (ATSDR 1992a). To protect against similar incidents occurring in the US, amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) prohibit the import of food containing residues of mercury-containing pesticides that are not registered for use in the US (EPA 1991a).

Mercury in Products

Mercury may be found in a variety of household products, including batteries, fluorescent light bulbs, electrical switches and thermometers. The use of mercury in many of these applications is regulated by US government agencies or controlled voluntarily by industry groups. As a result, industrial consumption of mercury in the US declined dramatically between 1982 and 1991. After increasing from 1687 metric tons in 1982 to 1884 metric tons in 1984, mercury consumption plummeted to 473 metric tons in 1991 (US Bureau of Mines, 1986, 1991). EPA in January 1993 proposed a regulation that would allow states, manufacturers and others to set up special collection programs to facilitate the recycling and proper management of hazardous consumer wastes. The proposed regulation would relax some of the stringent requirements for storage, transport, and permitting that normally apply to these wastes. The proposed regulation covers certain mercury-containing products such as batteries but does not include fluorescent lamps. A brief summary of product-specific activities is presented below.

Batteries. Alkaline and mercury-zinc batteries are the most commonly used mercury-containing batteries, although mercury is also found in carbon-zinc, silver oxide, zinc air, mercury-indium-bismuth, and mercury-cadmium batteries. Because of concerns about mercury in the municipal waste stream, battery manufacturers have taken action to reduce the amounts of mercury in batteries. The industry has announced its intention to reduce mercury in alkaline batteries to 0.025 per cent by weight by 1992, and eventually eliminate all mercury from batteries. According to one manufacturer, the use of mercury in one of its more common applications, film pack batteries, has already been discontinued (EPA 1991a). A major manufacturer has recently announced plans to discontinue production of mercury-zinc "button" batteries because of the development of an effective zinc-air replacement (Telzow, 1992). These measures have resulted in a significant decline in the use of mercury in the battery market. Between 1982 and 1991 the amount of mercury consumed first increased from 852 metric tons to 1024 metric tons and then declined to 78 metric tons in 1991 (US Bureau of Mines, 1986, 1991).

Paint. All uses of mercury in paint have been discontinued. Mercury was formerly used as a biocide in two categories of paints. Marine antifouling paints utilized mercury (principally mercuric oxide) as an agent to hinder the growth of algae after the paint was applied to the bottom of ships. Latex paints used a variety of mercury compounds [phenlymercuric acetate (PMA), 3-(chloromethoxy) propylmercuric acetate (CMPA), di(phenylmercury) dodecylsuccinate (PMDS) and phenylmercuric oleate (PMO)] as a biocide after its application, as well as a preservative to control microbial growth in the paint cans during storage. In 1972, the use of mercury as antifouling agent for marine applications was eliminated when the EPA cancelled all registrations of pesticides containing mercury for this use (EPA 1972). In July of 1990, all registrations for mercury biocides used in paints and coatings, except those for PMA, were voluntarily cancelled by the registrants (EPA 1990a, 1990b). These measures resulted in mercury consumption by the paint industry declining from 234 metric tons in 1982 to 6 metric tons in 1991 (US Bureau of Mines, 1986, 1991). In May of 1991, EPA announced the voluntary cancellation of the remaining PMA registrations, which were for exterior paints and coatings (EPA 1991a, 1991b).

Pesticides and Agricultural Products. For many years mercury and mercury compounds had been used as fungicides and insecticides for agricultural purposes. The EPA's Office of Prevention, Pesticides, and Toxic Substances, responsible for implementing the Federal Insecticide, Fungicide, and Rodenticide Act, has been active in regulating the use of mercury-containing pesticides in an effort to protect public health. In 1972, all existing registrations for mercury-containing fungicides and pesticides intended for application on food crops were cancelled by the EPA (EPA 1972). Four years later, in 1976, a series of cancellations further restricted the use of mercury-containing pesticides, effectively banning such products from all but specifically stated applications (e.g. treating Dutch Elm disease, freshly sawn lumber, brown mold, and outdoor fabrics and textiles) (EPA 1976a, 1976b, 1976c). EPA either has cancelled or has received requests for voluntary cancellation for all of these remaining registrations. There is no current production of mercury pesticides in the US.

Special Paper Coatings. Mercury bromide and mercury acetic acid are used in the coating of specialized paper and film used for scanning off cathode ray tubes. Only two companies manufacture the paper and film, and they have announced that plans are being developed to phase out the use of mercury in the coating. It is predicted that by 1995, mercury will be eliminated entirely from use in this application (EPA 1991a).

Drugs. FDA regulates the safety of mercury-containing substances that are used in "Over-the-Counter" (OTC) drugs such as anorectal products, vaginal contraceptives, and topical antiseptics. FDA regulates OTC drugs through the formal publication of monographs that describe the conditions under which a product is "recognized as safe and effective and not misbranded" (FDA 1992). In a proposed monograph on vaginal contraceptives, FDA placed phenyl mercuric acetate and other mercury compounds in Category II "not generally recognized as safe" for OTC use because of the potential hazard to fetuses and breast-feeding infants. FDA also noted that safe substitutes for the mercury-containing compounds are available (FDA 1980). A proposed rule (in the form of an amended tentative final monograph) on OTC antimicrobial products placed elemental mercury and 12 mercury compounds in Category II "ingredients not generally recognized as safe for OTC first aid use" and four mercury compounds in Category III "ingredients for which the available data are insufficient to make a final determination for OTC first aid use." The monograph also recommends specific testing procedures for further evaluating the safety and efficacy of Category II and Category III products (FDA 1991). FDA is continuing its evaluation of all mercury-containing OTC drugs in order to make a final determination on their safety and efficacy (FDA 1993).

Cosmetics. Mercury compounds were previously used in skin bleaching creams and as preservatives in a variety of cosmetics. These uses of mercury have been prohibited by FDA. Current regulations allow mercury only as a preservative in cosmetics intended for use in the area of the eye and only if no effective and safe nonmercurial preservative is available. The concentration of mercury in eye-area cosmetics may not exceed 65 ppm (21 CFR 700.13).

Dental Amalgam. Dental amalgams are typically 40-50 per cent elemental mercury by weight and account for at least half of the approximately 200 million dental restorations performed in the US each year. Dental amalgams represent a significant source of overall mercury exposure and probably are the major source of elemental mercury vapor exposure to the general population. A recent report by the US Public Health Service (CCEHRP 1993) concludes, consistent with a number of similar evaluations cited in the report, that "current scientific evidence does not show that exposure to mercury from amalgam restorations poses a serious health risk in humans, except for an exceedingly small number of allergic reactions." However, the report cautions that there are significant gaps in the base of information relevant to assessment of chronic low-level mercury exposure. Substantial research is needed to reduce uncertainties and reach more definitive conclusions regarding health risks from dental amalgams. At present, FDA regulates dental mercury and amalgam alloys separately, as "class I" and "class II" devices, respectively. The CCEHRP report recommends that mercury and the alloys be treated as a single class II product. This would result in the maximum degree of control within the current regulatory framework for these types of products. The CCEHRP also recommends required disclosure of product ingredients by manufacturers of dental restoratives and improved education of dental providers and patients regarding adverse reactions. These steps could help in identifying and reducing the occurrence of sensitization reactions among dental patients. The use of amalgam has declined in recent years because of a decrease in dental caries and the use of alternative materials and techniques. Additional education on alternatives and proper handling, including waste management, could further reduce mercury exposures to patients and dental practitioner and reduce the environmental releases of mercury from dental offices.

Fluorescent Lamps and High Intensity Discharge Lamps (HID)

Mercury has long been used in a variety of lamps, ranging from common household fluorescent light tubes to high intensity discharge lamps used for outdoor lighting. High power HID lamps (e.g. 1000 watt lamp) can contain up to 250 mg mercury. The amount of mercury contained in standard four-foot and eight-foot fluorescent tubes ranges from 35 to 75 mg. In 1990, the average quantity of mercury in a standard four-foot lamp was about 40 mg. Major manufacturers estimate that they will be able to reduce the average mercury content in a four-foot lamp to 27 mg by 1995 (NEMA 1992a). Currently, most fluorescent lamps are simply disposed of as municipal or industrial solid waste. Combustion of these wastes is of particular concern because current emission controls on many municipal combustors are relatively ineffective in capturing mercury. The mercury level in many fluorescent lamps exceeds the RCRA Toxicity Characteristic limit (0.2 mg/litre in the leachate, following a standard extraction procedure), thus classifying the lamps as hazardous waste. EPA's Office of Solid Waste is seeking comment on two alternative approaches for the management of mercury-containing lamps. One approach in the proposal is to exclude mercury lamps from classification as hazardous waste under the condition that the lamps be managed in a state-controlled landfill or recycling facility. The other approach is to include mercury in a proposed special collection system that is intended to facilitate the recycling and safe disposal of non-industrial wastes (EPA 1994).

Mercury in Cultural Practices

Certain cultural groups from Latin America and the Caribbean use mercury in folk medicines and in other cultural and religious practices. The US EPA is working with organizations that represent and assist these groups in order to provide information about mercury risks. Written materials and radio broadcasts are being developed. Information will be provided in English and other native languages.

Occupational Standards for Mercury

The Occupational Safety and Health Administration (OSHA), a branch of the Department of Labor, regulates exposures to mercury in the workplace by establishing Permissible Exposure Limits (PEL). The 1989 PEL update included three different standards for mercury and its compounds: an 8-hour time weighted average (TWA) of 0.05 mg/m^3 for mercury vapor and 0.01 mg/m^3 for alkyl mercury compounds; a Short Term Exposure Limit (STEL), a maximum level for a 15-minute period, of 0.03 mg/m^3 for alkyl mercury compounds; and a ceiling limit, a maximum never to be exceeded in the workplace, of 0.1 mg/m^3 for aryl and inorganic mercury (OSHA 1989). All forms of mercury were assigned a skin notation, indicating that the substance is absorbed through the skin, and therefore, skin contact should be avoided. However, the US Court of Appeals in July, 1992 struck down all PELs established by the 1989 regulation, including those standards set for mercury. OSHA announced in March, 1993 that it would not appeal the court ruling, meaning that all PELs will revert to previous standards. The earlier standards are: a ceiling limit of 0.1 mg/m^3 for elemental mercury, inorganic mercury and alkylmercury compounds; an 8-hour TWA of 0.01 mg/m^3 for alkylmercury compounds, and a ceiling limit of 0.04 mg/m^3 for alkylmercury compounds (OSHA 1993). Because the current enforceable standards are not based on current data and risk assessments, OSHA does not necessarily consider these standards to be adequately protective. Furthermore, many companies are expected to voluntarily follow the previous standards.

The National Institute for Occupational Safety and Health (NIOSH), which makes recommendations to OSHA, defines an additional limit called the IDLH (Immediately Dangerous to Life and Health) level, defined as the maximum environmental concentration of a contaminant from which one could escape within 30 minutes without any escape-impairing symptoms or irreversible health effects. The IDLH is 28 mg/m^3 for elemental mercury vapor and 10 mg/m^3 for organo (alkyl) mercury compounds. Other NIOSH standards for mercury, as well as those of the American Conference of Governmental Industrial Hygienists (ACGIH), an independent association of professionals, correspond to the 1989 OSHA standards (ACGIH 1990, NIOSH 1990).

Nordic countries

Nordic countries have undertaken a number of joint initiatives towards protecting the environment.

Denmark, Sweden and Norway have signed the Ministerial Declaration of the Third International Conference on the Protection of the North Sea (Third International Conference on the Protection of the North Sea 1990). This declaration states that the inputs of mercury, via all pathways, are to be reduced between 1985 and 1995 by 70 per cent or more, provided that the use of best available technology or other low waste technology measures enables such a reduction.

Denmark, Finland and Sweden have through the Helsinki Commission (HELCOM), and their Declaration on the Protection of the Marine Environment of the Baltic Sea Area, adopted the goal of reducing emissions of mercury to water and air with 50 percent not later than 1995, using 1987 as a reference year. Further, the Contracting parties are to give priority to preventive measures on mercury and its compounds.

As Contracting Parties of the Paris Commission (PARCOM), Denmark, Sweden and Norway adopted the PARCOM Recommendation 89/3 on Programmes and Measures for Reducing Mercury Discharges from Various Sources.

On the commission of the Nordic Chemicals Group under the Nordic Council of Ministers, a consultant report describing Nordic experiences regarding the technological possibilities for reducing the use of mercury (Nordic Council of Ministers 1992) has been elaborated. The report concludes that there are technologically acceptable substitutes for most areas of application. For some applications, problems are still to be solved.

European Union

The European Union has regulated by different Directives the environmental pollution from mercury and the use of several mercury-containing products. A list of the relevant Directives is presented below.

EEC Directive 79/117, amended in 1991 by EEC Directive 91/188, for the phasing-out of the use of mercury in seed dressing in a few years.

EEC Directive 82/176 defines the limit values and quality objectives for mercury discharges from the chlor-alkali industry.

Emissions to water from industrial plants are regulated by EEC Directive 84/156 defining limit values and quality objectives for mercury discharges (to water) by sectors other than the chlor-alkali industry.

EEC Directive 89/369 sets limits on emissions to the atmosphere from new municipal waste incinerators as follows: 0.2 mg Cd+Hg/m^3.

EEC Directive 89/677 bans from ultimo 1991 the use of mercury in antifouling paint, preservation of wood, impregnation of heavy-duty industrial textiles and yarn intended for their manufacture, and in treatment of industrial waters.

Statement from the European battery industry (Europile)

In 1990, alkaline batteries that were "mercury-free" were introduced into the market. They have the same technical specifications as mercury-containing batteries, and if they are substituted completely for mercury-containing batteries a substantial reduction in the amount of mercury coming from exhausted alkaline batteries will be attained (see Figure 2.1 in Chapter 2). In 1994, the new batteries are expected to be "mercury-free".

From 1994, the use of mercury will be restricted to special purpose batteries which include miniature button batteries designed for use in hearing aids, calculators, photographic equipment and other technical uses. These batteries comprise less than 1 per cent by weight of all batteries sold.

The mercury oxide special purpose battery, responsible for 94 per cent of all mercury in batteries after 1994, will be collected separately for recycling or special disposal in accordance with the European Union legislation.

In accordance with the industry policy to reduce environmental pollutants at source, the mercuric oxide battery is being replaced as fast as technology will allow by low mercury-containing substitutes such as the zinc air and silver oxide batteries.

The mixing of special purpose and general purpose batteries in a collection scheme makes the identification of the specialities extremely difficult and increases the cost and complexity of their sorting and treatment. However, collection of special purpose batteries only for specific disposal is eased because:

- they will be easily identified by a special EU symbol for this purpose from March 1993;
- they constitute less than 1 per cent of all batteries sold and therefore their collection can easily be managed.

There is no environmental benefit to be gained by separate collection of general purpose batteries because:

- they already contain less than the European Union limits for mercury
- no general purpose batteries will contain mercury from 1994
- no economically or environmentally superior recycling techniques exist.

Statement from the European chlor-alkali industry (EURO CHLOR)

Emissions from the mercury cell chlor-alkali industry today

Accurate and detailed measurements made on the site of each producer show that the European chlor-alkali industry released not more than 25 tonnes of mercury to the environment (figure for 1992) and the United States chlor-alkali industry less than 12 tonnes to all media (in 1991).

Note that, if the United States and European chlor-alkali industry comprises each about 25 per cent of the world installed capacity, in Europe most of it is in mercury cell technology and in the United States, most of it is in diaphragm cell technology.

The sum 25 + 12 = 37 metric tonnes represents only 0.7 per cent of global mercury emissions.

In comparison, the single largest source of anthropogenic mercury emission is fossil fuel combustion, with probably much more than 1000 metric tonnes per year.

Evolution of the chlor-alkali industry

Over the last 20 years, American and European producers have significantly reduced levels of emissions of mercury to the environment.

The plants operate under very strict regulatory requirements limiting the emissions and discharges of mercury. Workplace safety is regulated.

Mercury emissions have been reduced by significant capital investments and by the industry’s commitment to environmental improvement.

In Europe, since 1977 mercury emissions per tonne of chlorine capacity have been reduced by 86.5 per cent.

In the United States since 1988, releases of mercury and mercury compounds by the industry have been reduced by 37.6 per cent.

Potential exists to make further substantial reductions over the next 15 years. This will be brought about through combination of plant closure, selective conversion to other technologies, upgrading of existing plant standards, and improvement to mercury containment.

Solid wastes

More and more facilities are now providing mercury recovery from solid wastes, so that mercury is reused by a variety of processes. Wherever possible, the mercury is recovered by a variety of techniques such as washing or settling. Thermal desorption technology is also used to reduce mercury discharges to land. In the United States, for example, approximately 50 per cent of the facilities are currently employing mercury recovery systems.

The remaining solid wastes containing mercury which are finally disposed of are completely contained by adequate methods:

- mercury in the form of inactive sulphide
- total encapsulation and containment within a membrane-lined site
- use of approved landfill sites

Monitoring around the landfills confirms the security of containment; there is no loss of mercury to the environment.

This explains why the consumption of mercury by the chlor-alkali industry is not in any sense equal to the quantity of mercury emitted to the environment.

Conclusions

1. Mercury is a hazardous material and it must be handled properly. OECD should determine whether current amounts of mercury being released to the environment are not protective of human health and the environment. If this is true, OECD needs to identify the significant sources and recommend steps to reduce such sources.

2. The chlor-alkali industry, in Europe and the United States, is a very small and decreasing source of mercury to the environment.

3. The huge investment to eliminate this source and replace mercury cells with membrane (e.g. diaphragm) cells cannot be justified on any economic grounds and will not show any significant reduction in environmental concentrations.

4. There is no sustainable environmental argument to justify the necessary investment.

ANNEX A (TO CHAPTER 5)

MERCURY RISK REDUCTION ACTIVITIES:

SUMMARY TABLES

Actions for use of mercury in batteries

Country	Actions
Australia	Different regulations in different states.
Austria	Ordinance on batteries (514/1990): batteries and accumulators may not contain more than 0.001 per cent mercury.
Belgium	EEC Directive (91/157/EEC) for batteries and accumulators containing certain dangerous substances. Directive implemented in 1988.
Canada	Under the Canadian Environmental Choice Guidelines the following levels of mercury in batteries have been set: zinc-air batteries for hearing aids: a maximum of 40 mg/Ah rating on mercury content. Mercury reduction for cylindrical batteries: max. 0.02 per cent mercury by weight by July 1, 1993. Reduced mercury content in alkaline manganese button or coin batteries to max. of 25 mg per cell. Elimination of mercury in batteries by 1994-96 time-frame is an industry voluntary commitment and only guidelines.
Denmark	EEC Directive (91/157/EEC) for batteries and accumulators containing certain dangerous substances. Directive implemented 1 January 1993.
Finland	Regulations concerning the use, delivery, labelling, and collection of mercury-containing batteries are under preparation. The regulations bring into force the EEC Directives on batteries and accumulators (91/157/EEC and 93/86/EEC).
France	EEC Directive (91/157/EEC) for batteries and accumulators containing certain dangerous substances. Directive implemented 1 January 1993.
Germany	A ban of alkaline-manganese batteries with more than 0.025 per cent mercury from 1 January 1993. An obligation to label batteries containing more than 0.025 per cent mercury or more than 25 mg mercury/battery cell. For special applications, i.e. at extreme temperatures, batteries up to 0.05 per cent mercury are allowed. Strategy: To ensure that batteries are collected separately, and to raise the recycling rate of batteries.
Ireland	EEC Directive (91/157/EEC) for batteries and accumulators containing certain dangerous substances. Directive implemented 1 January 1993.
Japan	Guideline of Ministry of International Trade and Industry; Production of mercuric oxide batteries must stop completely by the end of 1995. (Production of mercuric oxide batteries for hearing aid application, which amount is about 80 per cent of the total mercuric oxide batteries, was already stopped completely in March 1994.)
Netherlands	EEC Directive (91/157) for batteries and accumulators containing certain dangerous substances implemented on January 1993.
Norway	It is prohibited to manufacture, export, import or sell zinc/carbon and non-rechargeable alkaline manganese batteries which contain 0.001 per cent or more mercury by weight. After 1-1-95, the ban will include all types of batteries (even button cells). Packaging containing individual button cell batteries of the type mercury oxide, silver oxide, zinc/air or other types containing a total of 0.025 per cent mercury, shall be labelled with recycling symbol. Retailers who sell batteries that shall be marked/labelled are obliged to accept comparable types of batteries for appropriate disposal from the consumers, free of charge.
Sweden	An ordinance (1989) prohibits the use of some types of alkaline manganese batteries. Rules are included on labelling and collection of environmentally dangerous batteries.
Switzerland	Regulations of 1986 with gradual decrease of mercury in alkaline and manganese batteries. Under revision.

Country	Actions
United Kingdom	EEC Directive (91/157/EEC) for batteries and accumulators containing certain dangerous substances. Directive implemented in phases beginning 1 January 1993.
United States	See table, "United States Risk Reduction Efforts for Mercury", at the end of this Annex.
European Union	EEC Directive (91/157/EEC) for batteries and accumulators containing certain dangerous substances. Prohibition of sale of alkaline manganese batteries with more than 0.025 per cent mercury, except for those for prolonged use in demanding conditions where the limit is 0.05 per cent mercury. Directive implemented in Member States from 1 January 1993. Alkaline manganese button cells and accumulators consisting of button cells exempted. The Directive also gives an obligation to ensure that batteries are collected separately and to raise the recycling rate of batteries.

Legislation for use of mercury in fluorescent tubes, electrical equipment, dental products, products for laboratory use, and thermometers

Country	Actions
Australia	Different regulations in different states; but no detailed information.
Austria	Regulation on fluorescent tubes with limit value of 15 mg/kg is in preparation for coming into force 1996. Limit values exist for effluents from amalgam separators, and maximum values for dental products.
Denmark	General ban on preparation for sale of mercury and mercury-containing products (more than 50 mg mercury/kg). Delayed ban and exemptions are given for different products. For instance, an immediate ban on mercury-containing thermometers, except for special purposes, as well as for dental fillings, will be implemented from 1 January 1995, with exemptions.
Germany	Mercury compounds or preparations containing mercury compounds must not be used or marketed for the following purposes: as antifouling; for the protection of wood, for the impregnation of heavy industrial textiles; for the production of yarns for heavy industrial textiles; for water processing in industrial, business and municipal sectors, independent of its use. Restrictions on use of mercury in thermometers, contacts and similar items are under discussion.
Finland	No specific regulation. Products containing mercury are classified as hazardous waste when disposed of. The Ministry of Social Affairs and Health has recommended that the use of amalgams in dental fillings should cease by the year 2000.
Netherlands	No regulation.
Norway	A ban on the production, import and sale of mercury-containing thermometers has been notified.
Sweden	No regulation of fluorescent tubes. From 1 January 1992, mercury in clinical glass thermometers is prohibited for import, manufacture and sale in Sweden. The same applies for other types of thermometers, measuring instruments and most electrical components containing mercury from 1 January 1993. Exemptions are given from the ban. It is not prohibited to use instruments that were bought before the ban came into force. The future strategy is to reduce all use of mercury. The Swedish Government has decided that the use of mercury amalgams in fillings of milk-teeth and in fillings of young people up to the age of 19 should cease from 1 July 1995. It is further decided that the use of mercury amalgams in fillings of adults should end by 1997.
Switzerland	Regulations in 1986 with a ban on use of mercury in all products. A list of exemptions is given, with gradual reduction of mercury in the products according to technical possibilities.
United Kingdom	There is no specific legislation controlling the supply of these products. Disposal of the products is covered by waste regulations.
United States	See table, "United States Risk Reduction Efforts for Mercury", at the end of this Annex.

Regulations for use of mercury in paints

Country	Actions
Australia	Restricted use.
Austria	All mercury compounds banned since 1990 (Ordinance 577/1990).
Belgium	All mercury compounds banned from 19 December 1991. EEC Directive 89/677/EEC.
Canada	Under the Hazardous Products Act, mercury is banned from use in paints applied to children’s products, and is voluntary eliminated from interior paint, but is allowed in exterior paints.
Denmark	Use forbidden since 1980.
France	All mercury compounds banned from 31 March 1992. EEC Directive 89/677/EEC.
Germany	Forbidden since 1983.
Finland	No general ban or restrictions on use of mercury in paints. The use of mercury in antifouling paints was banned in 1992.
Ireland	All mercury compounds banned by end of 1992. EEC Directive 89/677.
Japan	Household paint must not contain organomercury compounds (regulated in 1973/74).
Netherlands	No application of mercury based on EEC Directive 89/677.
Norway	Mercury has not been used since 1970, owing to internal agreement among paint producers.
Sweden	No regulations exist. Swedish paint producers do not use mercury.
Switzerland	Use in paints forbidden for several years.
United Kingdom	Restriction in force for several years. EEC Directive with ban from 31 March 1992.
United States	See table, "United States Risk Reduction Efforts for Mercury", at the end of this Annex.
European Union	EEC Directive 89/677 bans from ultimo 1991 the use of mercury in anti-fouling paint, preservation of wood, impregnation of heavy-duty textiles and yarn intended for their manufacture, and in treatment of industrial water.

Regulations for use of seed dressing

Country	Actions
Australia	Restricted use in some states, e.g. as a fungicide in sugar cane setts. Forbidden in other states.
Austria	The use of mercury compounds in pesticides and seed dressing is forbidden since 1993 (Ordinance 97/1992).
Belgium	Forbidden for disinfection since 1 January 1990.
Canada	Registered pesticide containing mercury, but none for seed dressing.
Denmark	Forbidden since 1973, except for use in stock seed. From March 1992, all uses forbidden.
Finland	Forbidden since October 1992.
France	EEC Directive 91/188. Ban in force from 21 June 1991.
Germany	Forbidden since 1982.
Ireland	Banned from 30 June 1991.
Japan	The last registered mercury-containing pesticide was in 1973.
Netherlands	EEC Directive (79/117), exemption for seed potatoes until 1987.
Norway	Banned from 1 December 1991.
Sweden	May not be used without permission (1979). No permission given after 1 July 1988.
Switzerland	Forbidden for use after 1991.
United Kingdom	Banned from 1991.
United States	See table, "United States Risk Reduction Efforts for Mercury", at the end of this Annex.
European Union	EEC Directive 79/117, amended 1991 by Directive 91/188, for phasing out in a few years.

Legislation for control of emissions to air, water and soil from energy production, refuse incineration, metal mining and production, gold mining, dental clinics, crematoria, and other emission sources

Country	Actions
Australia	Different regulations in different states, but no detailed information on limit values.
Austria	Limit values depending on technical area for emissions to air between 0.1 and 0.05 mg/m^3; emissions to water 0.01 mg/litre.
Belgium	Base quality for normal surface water: 0.5 µg/litre. Emissions to surface waters (wastewater): max. 0.15 mg/litre. Monthly: max. 0.1 g/tonne chlorine produced. Chemical plants using mercury catalyst for production of other than vinylchloride: monthly: max. 5 g/kg used mercury. Fabrication of organic and non-organic mercury compounds; non-ferrous and treatment of mercury-containing toxic waste: monthly: max. 0.05 g/kg mercury utilized. Fabrication of primary batteries: monthly: max. 0.03 g/kg mercury utilized. Textile: max. 0.02 mg/litre. Cleaning of vessels: max. 0.01 mg/litre. Pigments, paints, inks; cleaning of ships and cars transporting fluids: max. 0.001 mg/litre. Pulp and paper industry: 0.
Canada	0.1 µg/litre in the Canadian Water Quality Guidelines for the protection of aquatic life.
Denmark	At present, no regulation of emissions to air from power plants. However, it is possible to adopt such regulation within the Danish Environmental Protection Act. Refuse incineration and power plants require an environmental approval from regional authorities. Danish regulations of emissions from waste incineration plants are based on EEC Directive 89/369. Emissions to water from industrial plants are regulated by EEC Directive 84/156. Main Danish principle: reduce mercury emissions by best available technology. Crematoria must hold an environmental approval before January 1, 1994. Guidelines for design and operation of crematoria are issued, but do not cover mercury. Some local authorities require permits for dental clinics; limits in wastewater of 5 g mercury/unit, year.
France	EEC Directives. Special order prohibits the incineration of waste containing mercury.
Finland	Emissions to air, water and soil are regulated by the Air Pollution Control Act, the Water Act, and the Waste Act. Emissions limits are set on a case-by-case basis during the environmental permit procedures. EEC Directives 89/369/EEC and 89/429/EEC (new municipal waste incinerators) and 84/156/EEC (mercury discharges to waters by sectors other than the chlor-alkali industry) have been implemented.
Germany	Energy production from burning of coal: Total concentrations of cadmium, mercury and thallium max. 0.2 mg/m^3. Wastewater: max. 0.05 mg mercury/litre. Refuse incineration: Emissions to air max. 0.05 mg/m^3. Wastewater: max. 0.05 mg mercury/litre. Metal mining and production: Wastewater from non-ferrous metal: max. 0.05 mg mercury/litre. Facilities with high production capacity: max. load 1 g/tonne produced metal (e.g. lead, copper, zinc). Dental clinics: Mercury load of raw wastewater from dental treatment must be reduced by 95 per cent before mixing with domestic sewage, amalgam separators are used. Other legislation exists for mixed industrial wastewater (0.001 mg mercury/litre).

Country	Actions
Ireland	No information; but EEC legislation in force.
Japan	Legislation for refuse incineration, metal mining and production, emissions to soil, emissions to water, fertilizer control act with limits for spreading of sewage sludge on agricultural soil.
Netherlands	Wastewater limits of industry (excluding chlor-alkali) in force since 1 July 1986: vinylchloride production: <0.1 g/1000 kg production capacity of VCM; other industry (including production of mercury catalysts, production of organic and anorganic mercury compounds and production of mercury-containing primary batteries): 0.03-5.0 g/kg processed mercury. Regulation on organic fertilizers: sewage sludge: <3.5 mg/kg to 31-12-1994; starting 1-1-1995: <0.75 mg/kg. clean sludge: <1.5 mg/kg to 31-12-1994. compost: <2.0 mg/kg to 31-12-1994; starting 1-1-1995: <0.3 mg/kg. clean compost: <0.7 mg/kg to 31-12-1994. very clean compost: <0.2 mg/kg since 1-1-1993. black soil: <0.2+0.0017(2L+H) mg/kg since 1-1-1993. "Tennis elbow shock absorber": ban starting 1-6-1993.
Norway	Specific limits are set in the discharge permits for each industrial and waste incineration plant, according to the general legislation on environmental protection. Waste incineration: limit for emissions to air is 0.1 mg mercury m^{-3}. Metal mining and production: specific limits (0.1-8 kg/year). Regulations restricting discharges from dental clinics have been proposed. Installation of mercury separators and separate collection of mercury-containing waste will be required. Mercury-containing waste has to be treated as hazardous waste. Future strategy: Further reduction in emissions.
Sweden	No specific limits apply for different activities. Instead, decisions on application permits are made on a case-by-case basis for each plant by the County Administrative Board and the National Licensing Board for Environmental Protection, which are empowered to prescribe measures to reduce pollution. Since 1985, dental clinics must install amalgam separators. For crematoria, Sweden has ongoing projects aiming at installing selenium filters to minimize the mercury emissions. The long term goal is to phase out on a voluntary basis all uses of mercury in Sweden. By the year 2010, the goal is to have reduced the use of mercury by 75 per cent.
Switzerland	Limits for emissions to air (1985). Limits for emissions to water (1975). Limits for emissions from dental clinics (1988). Limits for mercury in fertilizers (1986) and sewage sludge and compost (1992). Limits for mercury in soils (1986). For numeric values, see text.
United Kingdom	Energy production from burning of coal: EEC Directives and use of the best available technology not entailing excessive costs (BATNEEC). Maximum emission limit to air 0.6 mg mercury/m^3, to water 0.02 mg mercury/litre. Refuse incineration: EEC Directive 89/369. Metal mining and production and dental clinics: EEC Directive 84/156 with water quality objectives. No universal established limits. Crematoria: Similar to waste incineration plants; but no maximum limits for emissions to air. Emissions limits are set for individual sites through the authorization procedure.
United States	See table, "United States Risk Reduction Efforts for Mercury", at the end of this Annex.

Country	Actions
European Union	EEC Directive 89/369 sets limits on emissions to the atmosphere from new municipal waste incinerators and is as follows: 0.2 mg Cd+Hg/m^3. Emissions to water from industrial plants are regulated by EEC Directive 84/156 defining limit values and quality objectives for mercury discharges (to water) by sectors other than chlor-alkali industry.

Legislation for control of emissions to air, water, and soil from the chlor-alkali industry and future strategy for the chlor-alkali industry

Country	Actions
Canada	Criteria for air: Current mercury release under the Canadian Environmental Protection Act. 5 g/day/tonne of rated capacity in ventilation gases exhausted from cell rooms of plant. 0.1 g/day/tonne where the source is the hydrogen gas stream from denuders or the gases exhausted from end boxes or retorts. No release from the ambient air tank. Maximum total allowance in a plant is 1.68 kg/day. Liquid effluent under the Fisheries Act is 0.0025 kg mercury/tonne of chlorine produced.
Denmark	EEC Directive 82/176. No production since 1991.
Finland	Emission limits are set on a case-by-case basis during the environmental permit procedure. EEC Directive 82/176 has been implemented.
France	EEC Directive 82/176. Elimination of mercury use by 2010.
Germany	EEC Directive 82/176. Mercury emission factor is limited to 1.5 g/tonne produced chlorine (Cl_2). Quality standard for wastewater is 0.2 g/tonne chlorine for a 24-hour sample. Elimination of mercury use by 2010.
Ireland	EEC Directive 82/176.
Netherlands	Wastewater emission limit in force since 1 July 1986: <0.5 g/1000 kg production capacity of chlorine.
Norway	The limit value for discharges to water is 0.25 g mercury/tonne chlorine capacity and for emissions to air 2.5 g mercury/tonne chlorine. The mercury-based process will be replaced with a mercury-free process by 1998.
Sweden	Application permits are given case-by-case. Atmospheric emissions are today less than 2 g mercury/tonne chlorine. Elimination of mercury use by 2010.
Switzerland	Water emission limit of 0.5 g/tonne chlorine capacity in force since 1983. Phasing out of mercury cell plants by 2010. Air emission limit of 2 g/tonne chlorine capacity by 1996.
United Kingdom	EEC Directive 82/176 with use of the quality objectives.
United States	See table, "United States Risk Reduction Efforts for Mercury", at the end of this Annex.
European Union	EEC Directive 82/176 defines the limit values and quality objectives for mercury discharges from the chlor-alkali industry.

United States
Risk Reduction Efforts for Mercury

Source		Actions
Environmental media	Drinking water	Maximum contaminant level (MCL)=0.002 mg/litre (40 CFR 141.62).
	Surface waters	Ambient Water Quality Criteria; water & organisms=0.144 µg/litre; organisms only=0.146 µg/litre (EPA 1986).
	Air	No ambient air standard.
	Soil	No soil standard.
Environmental sources	Air Point sources	Emissions from mercury ore processing facilities and mercury cell chlor-alkali plants are limited to a maximum of 2300 g/24-hr; emissions from sludge incinerations plants, sludge drying plants, or a combination of these that process wastewater treatment plant sludges are limited to a maximum of 3200 g /24-hr (40 CFR 61.52).
	Water point sources	Effluents from industrial facilities and municipal wastewater treatment facilities are regulated through industry-specific pre-treatment standards and effluent guidelines for existing and new sources of pollution and are based on the limits of the available control technology (40 CFR 401, 403, Appendix A).
	Sewage sludge	Permissible levels of mercury in municipal wastewater treatment sludges: 17 mg/kg dry wt. and cumulative load of 17 kg/hectare for agricultural land; 17 mg/ kg dry wt. and annual load of 0.85 kg/hectare for home garden or lawn; 57 mg/kg dry wt. for other land application; 100 g/kg dry wt. for surface disposal.
	Mercury-containing wastes	Any solid waste (including soil that is being disposed of) is considered a hazardous substance and prohibited from disposal in RCRA Subtitle D (non-hazardous) landfills if its leachate contains 0.2 mg/litre mercury or greater (40 CFR 261.24); land disposal in RCRA Subtitle C (hazardous waste) landfills is allowed only after prescribed treatment to reduce mercury in extract to 0.2 mg/litre. (40 CFR 302.4, 268, 262.270).
	Foodstuffs or feed	Action level for methylmercury in fish, shellfish, and other aquatic animals = 1 ppm (FDA CPG 7180.07); the import of foods containing the residue of mercury-containing pesticides that are not registered for use in the US is prohibited.
Products	Batteries	The battery industry has announced its intention to reduce mercury in alkaline batteries to 0.025 per cent by weight by 1992; it is predicted that approximately 5 per cent of the mercury in batteries will be recovered through recycling in 1995 and approximately 20 per cent by 2000 (EPA 1991A).
	Paints/pigments	All uses of mercury in paints have been discontinued (EPA 1972, 1990a, 1990b, 1991a, 1991b).
	Dental uses	US Public Health Service has recently studied risks from mercury amalgams and recommended tighter controls on dental uses of mercury and further research to reach more definitive conclusions on risk (CCEHRP 1993).
	Lighting	Because many fluorescent lamps are classified as RCRA Hazardous Waste under current test procedures, EPA is evaluating options for lamp disposal. Major options are 1) conditional exclusion of lamps from hazardous waste management, and 2) handling of lamps in a special collection system for other "low-grade" and small quantity hazardous wastes such as batteries and household pesticides.

United States
Risk Reduction Efforts for Mercury

Source		Actions
	Pesticides	No current production of mercury-containing pesticides. All former registrations have been cancelled or requests for voluntary cancellation have been received.
	Special paper coatings	The only two companies that manufacture these products have announced that plans are being developed to phase out the use of mercury in the coatings; it is predicted that by 1995 mercury will be eliminated entirely from this application (EPA 1991a).
	Drugs	Removal or restriction of mercury in "over-the-counter" drugs such as anorectal products and topical antiseptics; request for additional data on other OTC mercury antimicrobials.
	Cosmetics	The use of mercury as a preservative or antimicrobial is limited to eye-area cosmetics or ointments in concentrations less than 60 ppm (21 CFR 700.13)
Environmental health	Occupational standards	A ceiling limit of 0.1 mg/m^3 for elemental mercury, inorganic mercury, and alkylmercury compounds; an eight-hour TWA of 0.01 mg/m^3 for alkylmercury compounds, and a ceiling limit of 0.04 mg/m^3 for alkylmercury compounds. NOTE: more stringent standards were recently overturned in US court. The previous standards were: an 8-hour time weighted average (TWA) of 0.05 mg/m^3 for mercury vapour and 0.01 mg/m^3 for alkyl mercury compounds; a Short Term Exposure Limit (STEL), a maximum peak for a period not exceeding five minutes in any two hours, of 0.03 mg/m^3 for alkyl mercury compounds; and a ceiling limit, a maximum never to be exceeded in the workplace, of 0.1 mg/m^3 for aryl and inorganic mercury. All forms of mercury were assigned a skin notation, indicating that the substance is absorbed through the skin and therefore skin contact should be avoided (OSHA 1989).

APPENDIX 1-7

Appendix 1 Production of Mercury from Ores and Concentrates in Metric Tonnes (Metallgesellschaft 1992)

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Country/continent
76	53	–	–	–	–	–	–	–	–	–	Germany, FR
252	159	–	–	–	–	–	–	–	–	–	Italy
1560	1540	1416	1520	1539	1471	1533	1499	967	962	52	Spain
67	71	65	80	130	147	144	135	160	140	74	Finland
–	–	52	72	88	75	67	70	51	37	*35	Yugoslavia
1955	**1823**	**1533**	**1672**	**1757**	**1693**	**1764**	**1704**	**1178**	**1139**	**161**	**Europe**[1]
204	246	162	182	226	262	211	97	202	47	25	Turkey
204	**246**	**162**	**182**	**226**	**262**	**211**	**97**	**202**	**47**	**25**	**Asia**[1]
877	386	828	586	801	764	756	662	587	637	431	Algeria
877	**386**	**828**	**586**	**801**	**764**	**756**	**662**	**587**	**637**	**431**	**Africa**
3	2	4	2	1	–	–	–	–	–	–	Dominican Republic
240	295	221	384	394	185	124	345	651	735	*720	Mexico
962	888	864	657	570	*510	*140	*520	*470	*500	*40	United States
1205	**1185**	**1089**	**1043**	**965**	**695**	**264**	**865**	**1121**	**1235**	**760**	**America**
4241	**3640**	**3612**	**3483**	**3749**	**3414**	**2995**	**3328**	**3088**	**3058**	**1377**	**Western countries**
153	151	144	152	158	168	164	168	131	126	75	Czechoslovakia
1700	1700	1700	1600	1600	1500	1650	1650	1500	1400	1200	USSR*
800	800	850	800	800	850	900	900	1200	930	1000	China, PR*
2653	**2651**	**2694**	**2552**	**2558**	**2518**	**2714**	**2718**	**2831**	**2456**	**2275**	**Eastern countries**
6894	**6291**	**6306**	**6035**	**6307**	**5932**	**5709**	**6046**	**5919**	**5514**	**3652**	**Total World**

[1] Excluding "eastern countries"

* Estimated

Appendix 2 Use categories of mercury in 13 countries (metric tonnes/year)

Use Category	Denmark			Sweden		Norway		Netherlands		Finland	US	UK	France	Japan	Germany	Canada	Switzerland		Belgium	
Year	77/78	82/83	1990 *	1988	1991	1985	88/90	1980	1989	1987	1989	89/90	90/92	1989	1985	1982/91	1986	1990	1985	1990
Batteries	7.0	4.7	0.9	5.1	2.0	3.0	0.4	8.0	2.4	1.8	250.0	16.1	10.0	117.5	61.0	4.3	12.0	3.5	6.2	1.2
Thermometers				1.4	1.2	2.0	0.8			1.6		1.0	12.5		6.2	4.0	1.0	0.8	2.0	1.0
Tooth fillings	4.0	3.1	2.0	4.0	1.7	2.0	1.9	7.0	5.5	1.2	39.0	11.4	16.0	2.8	24.1	10.0	1.7	1.4	3.7	3.7
Pesticides as seed dressing	2.3	0.9	0.0	0.0	0.0	1.0	0.1			4.0		9.0	0.0	0.0	0.0	2.0	0.5	0.0	1.3	0.0
Laboratory	2.0	0.7		0.1	0.1	0.3	0.2	1.0		1.5	18.0				29.6	4.0			0.1	0.1
Hospital equipment				0.2																
Measurement equipment	3.0	2.5	2.0	0.3	0.5	0.2	0.1	2.8	<2.8		87.0				1.2	24.0				
Electrical:			1.0											6.9						
switches				2.5	2.9	<0.1	<0.1	1.3	<1.3		141.0				0.6				1.9	1.5
light sources				0.3	0.3	<0.2	<0.2			0.1	31.0		0.5		4.2	4.5	0.3	0.3	0.2	0.2
Paint		0.0	0.0	0.0	0.0					0.0	192.0			0.0	0.3	2.0				
Industry:														23.5						
chlor-alkali		3.0	3.0	0.5	0.2		<0.1	4.0	1.0	3.5	381.0	52.0	21.1		41.8	1.9			34.1	30.5
other				0.2	0.2						40.0				3.9		2.0	2.0		
Other uses	11.7	1.1	1.0			0.0					35.0		1.1	18.6	39.2		2.2	2.2	1.0	1.0
TOTAL USE	30.0	16.0	9.9	14.6	9.1	8.7	3.7	24.1	8.9	13.7	1214	89.5	61.2	169.3	212.1	56.7	19.7	10.2	50.5	39.2

Notes: A blank indicates no information.

Germany: Consumption in batteries in 1990: 12 metric tonnes.
Consumption in thermometers 1987-1990: 11-15 metric tonnes/year.
Consumption in tooth fillings in 1990 (including the new states): 25-30 metric tonnes
Consumption in laboratories is a mean of the figures from 1973-1984
Consumption in paint is zero in 1990 and 1991
Consumption in chlor-alkali industry (including the new states): 60 metric tonnes in 1991 and 37 in 1992
Canada: Consumption in batteries are from 1991. Seed dressing is zero. Other pesticides: 2.0 metric tonnes.
Finland: Consumption in batteries, tooth fillings, seed dressing and light sources are figures from 1991.

Appendix 3 Relative consumption of mercury in 13 countries

Use Category	Denmark			Sweden		Norway		Netherlands		Finland	US	UK	France	Japan	Germany	Canada	Switzerland		Belgium		Total
Year	**77/79**	**82/83**	**1990**	**1988**	**1991**	**1985**	**88/90**	**1980**	**1989**	**1987**	**1989**	**89/90**	**90/92**	**1989**	**1985**	**1982/91**	**1986**	**1990**	**1985**	**1990**	**1980s**
Batteries	23.3	29.4	9.1	34.9	22.0	34.6	10.7	33.2	27.0	13.1	20.6	18.0	16.3	69.4	28.8	7.6	61.1	34.3	12.3	3.1	25.1
Thermometers				9.6	13.2	23.1	20.1			11.7		1.1	20.4		2.9	7.1	5.1	7.9	4.0	2.6	1.7
Tooth fillings	13.3	19.4	20.2	27.4	18.7	23.1	49.9	29.0	61.8	8.8	3.2	12.7	26.1	1.7	11.4	17.6	8.7	13.7	7.3	9.4	7.0
Pesticides as seed dressing	7.7	5.6				11.0	3.2			29.2		10.1				3.5	2.5	0.4	2.6		0.9
Laboratory	6.7	4.4		0.7	1.1	3.5	5.4	4.1		10.9	1.5				14.0	7.1			0.2	0.2	2.7
Hospital equipment				1.4																	
Measurement equipment	10.0	15.6	20.2	2.1	5.5	2.3	2.7	11.6	<0.1		7.2				0.6	42.3					5.9
Electrical:			10.1											4.1							0.4
switches				17.1	31.9	<0.1	<0.1	5.4	<0.1		11.6				0.3				3.8	3.8	7.5
light sources				2.1	3.3	<0.1	<0.1			0.7	2.6		0.8		2.0	7.9	1.3	2.5	0.4	0.5	2.1
Paint											15.8				0.1	3.5					9.6
Industry:														13.9							1.2
chlor-alkali		18.8	30.3	3.4	2.2			16.6	11.2	25.5	31.4	58.1	34.5		19.7	3.4			67.5	77.8	28.4
other				1.4	2.2						3.3				1.8		10.2	19.6			2.4
Other uses	39.0	6.9	10.1			0.2					2.9		1.8	11.0	18.5		11.2	21.6	2.0	2.6	5.0
TOTAL USE	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10012

Appendix 4 Use of mercury in the United States 1959-1990 (metric tonnes/year)

Use category	1959	1968	1978	1984	1989	1990	1959	1968	1978	1984	1989	1990
	Metric tonnes/year						Relative consumption					
Agriculture	110	118	21	0	0	0	5.8	4.5	1.2	0.0	0.0	0.0
Amalgation	9	9	0.5	0	0	0	0.5	0.3	0.0	0.0	0.0	0.0
Catalytic	33	66	29	12	0	0	1.7	2.5	1.7	0.7	0.0	0.0
Dental	95	106	18	49	39	45	5.0	4.0	1.0	2.7	3.2	6.3
Electric light					31	34					2.6	4.7
Wiring/switches					141	69					11.6	9.6
Batteries	426	677	619	1170	250	107	22.5	25.9	35.4	65.1	20.6	14.9
Chlor-alkali	201	602	385	253	381	248	10.6	23.0	22.0	14.1	31.4	34.4
Laboratory	38	69	14	8	18	31	2.0	2.6	0.8	0.4	1.5	4.3
Instruments	351	275	120	98	87	107	18.6	10.5	6.9	5.5	7.2	14.9
Paint	121	369	309	160	192	21	6.4	14.1	17.7	8.9	15.8	2.9
Paper/pulp	150	14	0.5	0	0	0	7.9	0.5	0.0	0.0	0.0	0.0
Pharmaceuticals	59	15	15	0	0		3.1	0.6	0.9	0.0	0.0	0.0
Metals for inventory/other	298	298	216	48	75	58	15.8	11.4	12.4	2.7	6.2	8.1
TOTAL	1891	2618	1747	1798	1214	720	100	100	100	100	100	100

Appendix 5 Mercury Content of Rocks

(modified after Jonasson and Boyle 1979)

Rock type	Range	Mean (µg/kg)
Igneous		
Ultrabasic rocks (dunites, kimberlites, etc.)	7-250	168
Basic rocks		
Intrusives (gabbros, diabase, etc.)	5-84	28
Extrusives (basalt, etc.)	5-40	20
Intermediate rocks		
Intrusives (diorites, etc.)	13-64	38
Extrusives (andesites, etc.)	20-200	66
Acid rocks		
Intrusives (granites, granodiorites, syenite, etc.)	7-200	62
Extrusives (rhyolite, trachyte, etc.)	2-200	62
Alkali-rich rocks (nepheline syenites, phonolites, etc.) – (data mainly from Khibina and Lovozero massifs, USSR)	40-1400	450
Sedimentary		
Recent sediments		
Stream and river sediments	10-700	73
Lake sediments	10-700	73
Ocean sediments	<10-2000	100
Sandstone, arkose, conglomerate, etc.	<10-300	55
Shales and argillites		
Shales, mudstones and argillites	5-300	67-437
Carbonaceous shales, bituminous shales, etc.	100-3250	
	40-220	40
Limestone, dolomite, etc.	40- 60	25
Evaporites	20-200	30
Gypsum, anthydrite	20-200	30
Halite, sylvite, etc.		
		120
Rock phosphate (Florida)		
Metamorphic:		
Quartzites, etc.	10-100	53
Amphibolites	30- 90	50
Hornfels	35-160	225
Schists	10-1000	100
Gneisses	25-100	50
Marble, crystaline dolomites, etc.	10-100	50

Appendix 6 Mercury content of various sectors in nature (modified after Jonassen and Boyle 1979)

Sector	Range	Remarks/Mean
Volcanic exhalations, soil, air		
Atmosphere	2-10 ng/m^3	Higher values in industrial areas
Air over mercury deposits	30-1600 " "	Lower values (0.5) over oceans
Soil air over mercury deposits	0-2000 " "	Highly variable
Volcanic exhalations	100-9000 " "	Highly variable Data only from USSR, Hawaiian Islands
VOLCANIC CONDENSATES AND PRECIPITATES		
Fumarolic condensates	0.3-6 µg/kg	
Sulphuric and hydrochloric acids	0.2-72 " "	
Chloride, sulphate, fluoride and sulphur precipitates	1-14,000 " "	
Hydrous iron oxide precipitates	up to 0.1 per cent	Highly variable
Opaline silica sinters, etc. at hot spring orifices	up to 0.2 per cent	Highly variable Some contain cinnabar, metacinnabar, native mercury, etc.
FOSSIL FUELS		
Peat	60-330 µg/kg	
Coal	10-8.530 " "	Highly variable
Coal in mercuriferous basins	20-300,000 " "	Donbas and Donets basins, USSR
Crude oils	20-2,000 " "	
Petroleum crudes in mercuriferous belts	1900- 21,000 " "	Libya, USA
Natural gas	Saturated with mercury vapour	Data only from Cymric field, California
Natural gas for consumer use	0-450 mg/m$_3$	Data only from Cymric field, California
Bitumens, solid hydrocarbons, asphalts, etc.	1-3 µg/m$_3$ 2000-900,000 µg/kg	Germany Germany Some bitumens and solid hydrocarbons such as idrialite are greatly enriched (up to percentages) in mercury
LIVING ORGANISMS		
Marine plants	0.1-37 µg/kg fresh nt.	Limited data
Terrestrial plants	0-40 " " "	30-700 (in the dry plant)
Terrestrial plants in vicinity of mercury deposits	200-30,000 " " "	In the dry plant
Marine animals, molluscs, fish, seals, etc.	0.1-200 " " "	
Terrestrial (freshwater) animals, fish, birds, grayfish etc.	0.1-200 " " "	Contents up to 5000 or more recorded
Terrestrial (land) animals, man, birds etc.	1-100 " " "	
SOILS AND GLACIAL DEPOSITS		
Normal soils	20-150 µg/kg	70 µg/kg
Normal tills, glacial clay, sand, etc.	20-100 "	80 "
Soils, tills, etc. near mercury deposits, sulphide deposits, etc.	up to 250 mg/kg	
Soil horizons (normal)*		
A (humic)	60-200 µg/kg	161 "
B	30-140 "	89 "
C	25-150 "	96 "
Soil horizons (near mercury deposits)*		
A (humic)	200-1860 "	480 "
B	140-605 "	275 "
C	150-554 "	263 "
Natural waters		
Rainwater, snow	0.01-0.48 µg/kg	
Normal stream, river and lake waters	0.001-0.1 µg/litre	
Coal mine waters (Donets Basin, USSR)	1-10 "	
Stream and river waters near mercury deposits	0.5-100 "	
Oceans and seas	0.0005-0.1 "	
Hot springs and certain mineral waters	0.01-2.5 "	
Normal groundwaters	0.0001-0.02 "	
Groundwaters and mine waters near polymetallic sulphide deposits	1-1000 "	
Oil field and other saline waters	0.1-230 "	

* Examples from Clyde Forks area, Ontario.

Appendix 7 Mercury emissions in the EC (metric tonnes per year) in 1989 (Maxson et al.1991)

	Destination of immediate emissions			
Source/activity	**Air**	**Water**	**Land**	**Total**
Mercury mining	10	?	20	30
Secondary production	5	< 1	15	21
Non-ferrous metal production/refining:				
· zinc/cadmium	4	< 1	16	20
· lead	1	< 1	2	3
· copper	1	< 1	1	2
Subtotal: Non-ferrous	**6**	**1**	**19**	**26**
Fossil fuels:				
· coal	48	< 1	12	60
· oil	24	–	–	24
· natural gas	4	–	–	4
Subtotal: Fossil fuels	**76**	**< 1**	**12**	**88**
Industrial production:				
· iron/steel	4	2	28	34
· chlorine/caustic	23	5	150	178
· industrial catalysts	?	< 1	?	< 1
· cement	2	–	26	28
· phosphate fertilizer	< 1	1	3	4
· mercuric oxide, other chemicals	?	?	?	?
· others, especially sulphuric acid	*	*	*	*
Subtotal: industrial	**29**	**8**	**207**	**244**
Product use:				
· batteries	33	< 1	100	133
· dental amalgams	8	14	24	46
· electric lighting and equipment	10	< 1	30	40
· measuring/control instruments	6	< 1	19	25
· laboratory applications	1	1	6	8
· phosphate fertilizer	–	–	11	11
· industrial catalysts	4	< 1	12	16
Subtotal: Product use	**62**	**17**	**202**	**281**
Cremation/burial	4	–	6	10
Sludge waste disposal	3	2	28	33
Dredging	< 1	6	20	26
Totals	**196**	**35**	**529**	**760**
% of total	**26**	**5**	**69**	**100**
Grams of mercury per capita	**0.6**	**0.1**	**1.6**	**2.3**

REFERENCES

ACGIH (1990) Threshold limit values and biological exposure indices. 5th ed. American Conference of Governmental Industrial Hygienists, Cincinnati, as referenced in ATSDR 1992.

ALLARD (1993) Amalgaam. Report on a literature study (in Dutch) – draft version.

Armands, G. (1967) Geochemical Prospecting of a Uraniferous Bog Deposit at Masugusbyn, Northern Sweden. In: Kvalheim, A. (ed.), Geochemical Prospecting in Fennoscandia. New York: Interscience, 127-154.

ATSDR (1992a) Case Studies in Environmental Medicine, Mercury Toxicity. US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. March.

ATSDR (1992b) Toxicological Profile for Mercury, Draft. US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

Bacci, E. (1989) Mercury in the Mediterranean. Mar. Pollut. Bull. 20:59-63.

Bayens, W. (1993) Modification of the Mercury Fluxes at the Air-Sea Interface. Water, Air and Soil Pollut. 56:731-744.

Boutron, C.F. (1986) Atmospheric Toxic Metals and Metalloids in the Snow and Ice Layers Deposited in Greenland and Antarctica from Prehistoric Times to Present. In: Toxic Metals in the Atmosphere, Nriagu, J.O. and Davidson, C.I. (eds.). Advances in Environmental Science and Technology 17:467-505.

British Geological Survey (1990) World Mineral Statistics 1988-89.

Buart-Menard, P. and Duce, R.A. (1987) in: Lead, Mercury, Cadmium and Arsenic in the Environment (SCOPE 31), Hutchinson, T.C. and Meema, K.M. (eds.), pp. 147-74.

CAAA (1990) US Clean Air Act Amendments Subsection 112(n)(1)(B).

Calasans, C.F., Malm, O. and Pfeiffer, W.C. (1993) Evaluation of atmospheric Hg contamination through the biological monitor *Tillandsia usneoides* (Bromeliaceae). In: Conference Proceedings (Allan, R.J and Nriagu, J.O., eds.), International Conference: Heavy Metals in the Environment, Toronto, Canada, 12-17 September 1993. Vol. 1, pp. 344-47.

Carpi, A., Weinstein, L.H. and Ditz, D.W. (1994) Bioaccumulation of Mercury by Sphagnum Moss near a Municipal Solid Waste Incinerator. Air And Waste 44:669-72.

Coker, W.B. and DiLabio, R.N.W. (1979) Initial Geochemical Results and Exploration Significance of Two Uraniferous Peat Bogs, Kasmere Lake, Manitoba. In: Current Research, Part B, Geological Survey of Canada, paper 79-1B, pp. 199-206.

Coker, W.B., Hornbrook, E.H.W. and Carmeron, E.M. (1979) Lake Sediment Geochemistry Applied to Mineral Exploration. In: Hood, P.J. (ed.), Geophysics and Geochemistry in the Search for Metallic Ores. Geological Survey of Canada, Economic Geology Report 31, pp. 435-478.

CCEHRP (1993) Dental Amalgam: A Scientific Review and Recommended Public Health Service Strategy for Research, Education and Regulation. Committee to Coordinate Environmental Health and Related Programs, US Public Health Service. January.

CCRX (1993) Pieters, H., Hagel P. and Ruiter, A. (1993) Kwik in Milieu en Voeding in Nederland, Coördinatie Commissie voor de metingen van Radioactiviteit en Xenobiotische stoffen. The Netherlands.

CEPA (Commenwealth Environment Protection Agency) (1994) Comments to the mercury OECD report.

Cossa, D., Thibaud, Y., Romeo, M. and Gnassia-Barelli, M. (1990) Le Mercure en Milieu Marin : Biogéochimie et Écotoxicologie. Rapport Scientifique et Techniqiue IFREMER 18. Nantes, 130 pp.

Craig, P.J. (1988) Organometallic Compounds in the Environment. Longman.

CUWVO (1991) De Waterkwaliteit van Nederland in 1990. Coördinatie Commissie Uitvoering Wet Verontreinniging Oppervlaktewateren. The Netherlands.

DHHS (1993) Dental Amalgam: A Scientific Review and Recommended Public Health Service Strategy for Research, Education and Regulation. Final Report of the Subcommittee on Risk Management of the Committee to Coordinate Environmental Health and Related Programs. Department of Health and Human Services, Public Health Service, the Netherlands.

Dilabio, R.N.W. (1983) Geochemistry of Peat in the NEA/IAEA Athabasca Test Area. In: Cameron, E.M. (ed.), Uranium Exploration in Athabasca Basin, Saskatchewan, Canada. Geological Survey of Canada, Paper 82-11, pp. 133-38.

Dilabio, R.N.W. and Coker, W.B. (1982) Geochemistry of Peat Associated with Uraniferous Bedrock, Kasmere Lake Area, Manitoba. In: Davenport, P.H. (ed.), Prospecting in Areas of Glaciated Terrain – 1982. Canadian Institute of Mining and Metallurgy, pp. 179-94.

Dunn, E.E. (1987) Developments in Biogeochemical Exploration. In: Garland, G.D. (ed.), Exploration '87: Third Decennial International Conference on Geophysical and Geochemical Exploration for Minerals and Groundwater, Toronto. Special Volume, Ontario Geological Survey, 1989, pp. 417-438.

Edner, H., Faris, G.W., Sunesson, A., Svanberg, S., Bjarnson, J.O., Kristmannsdottir, H. and Sigurdsson, K.H. (1991) Lidar Search for Atmospheric Mercury in Icelandic Geothermal Fields. J. Geophys, Res. 96:2977-2986.

Environment Canada (1994) Letter from Commercial Chemicals Evaluation Division to VKI/OECD (17 June 1994).

Europile (1992) Batteries and the Environment. The Association of European Dry Battery Manufacturers, Bern.

EURO CHLOR (1994) Comments to OECD Mercury Draft Status Report – November 1993. Letter to BIAC (Business and Industry Advisory Committee to the OECD), 14 March 1994.

FDA (Food and Drug Administration, United States) (1980) Federal Register 45(241):82014, December 12, 1980.

FDA (Food and Drug Administration, United States) (1991) Federal Register 56(140):33644. July 22, 1991.

FDA (Food and Drug Administration, United States) (1992) Code of Federal Regulations, Vol. 21, Part 330.

FDA (Food and Drug Administration, United States) (1993) Personal communication to US EPA.

Fitzgerald, W.F. (1986) Cycling of Mercury between the Atmosphere and Oceans. In: Buat-Ménard, P., ed., The role of Air-sea Exchange in Geochemical Cycling. R. Reidel Publishing Company, 363-408.

Fitzgerald, W.F. (1993) Global Biogeochemical Cycling of Mercury. In: Conference Proceedings (Allan, R.J and Nriagu, J.O., eds.), International Conference: Heavy Metals in the Environment 1:320-323.

Fitzgerald, W.F., Mason. R.P. and Vandal, G.M. (1991) Atmospheric Cycling and Air-Water Exchange of Mercury over Mid-Continental Lacustrine Regions. Water, Air and Soil Pollution 56:745-767.

Garrett, R.G. (1994) Concentration of Metallic Elements in Continental Crust. Geological Survey of Canada.

GESAMP (1986) Review of Potentially Harmful Substances: Arsenic, Mercury and Selenium. IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Pollution. Geneva: WHO Reports and Studies 28.

Gill, G.A. and Fitzgerald, W.F. (1987) Mercury in Surface Waters of the Open Ocean. Global Biogeochemical Cycles 1:199-212.

Gill, G.A. and Fitzgerald, W.F. (1988) Vertical Mercury Distributions in the Oceans. Geochim. Cosmochim. Acta 52:1719-1728.

Godbold, D.L. (1991) Mercury-induced Root Damage in Spruce Seedlings. Water, Air and Soil Pollut. 56:823-831.

Hecky, R.E., Ramsey, D.J., Bodaly, R.A. and Strange, N.E. (1991) Increased Methylmercury Contamination in Fish in Newly formed Freshwater Reservoirs. In: Advances in Mercury Toxicology (Susuki, T., et al., eds.). New York: Plenum Press, 33-52.

Hoyer, M., Burke, J., Cleckner, L., Mukherjee, K. and Keeler, G. (1993) Mercury in Precipitation: A Multi-site Study. In: Conference Proceedings (Allan, R.J and Nriagu, J.O., eds.), International Conference: Heavy Metals in the Environment, 1:332-335.

Hultberg, H., Iverfeldt, Å. and Lee, Y.-H. (1993) Methylmercury Input/Output and Accumulation in Forested Catchments and Critical Loads for Lakes in Southwestern Sweden. In: Watras, C.J. and Huckabee, J.W. (eds.), Mercury Pollution: Integration and Synthesis. Boca Raton, Florida: Lewis Publishers.

IPCS (International Programme on Chemical Safety): see WHO.

IRIS (1992) Integrated Risk Information Systems. US Environmental Protection Agency, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, Ohio.

Jensen, A. and Iverfeldt, Å. (1994) Atmospheric Bulk Deposition of Mercury to the Southern Baltic Sea. In: Watras, C.J. and Huckabee, J.W. (eds.), Mercury Pollution: Integration and Synthesis. Boca Raton, Florida: Lewis Publishers.

Jensen, A. and Jensen, A. (1991) Historical Deposition Rates of Mercury in Scandinavia Estimated by Dating and Measurement of Mercury in Cores of Peat Bogs. Water, Air and Soil Pollut. 56:769-777.

Johansson, K., Aastrup, M., Anderson, A., Bringemark, L. and Iverfeldt, Å. (1991) Mercury in Swedish Forest Soils and Waters - Assessment of Critical Load. Water, Air and Soil Pollut. 56:267-281.

Kim, J.P. and Fitzgerald, W.F. (1986) Sea-air Partitioning of Mercury in the Equatorial Pacific Ocean. Science 231:1131-1133.

Kim, K.-H., Lindberg, S.E., Hanson, P.J., Meyers, T.P. and Owens, J. (1993) Application of Micrometeorological Methods to Measurements of Mercury Emissions over Contaminated Soils. In Conference Proceedings (Allan, R.J and Nriagu, J.O., eds.), International Conference: Heavy Metals in the Environment 2:328-331.

Krabbenhoft, D.P. and Babiarz, C.L. (1992) The Role of Groundwater Transport in Aquatic Mercury Cycling. Water Resources Research 28(12):3119-3128.

Kiørboe, T., Møhlenberg F. and Riisgård, H.U. (1983) Mercury Levels in Fish, Invertebrates and Sediments in a Recently Recorded Polluted Area (Nissum Broad, Western Limfjord, Denmark). Mar. Pollut. Bull. 14:21-24.

Lamersdorf, N.P., Godbold, D.L. and Knoche, D. (1991) Risk Assessment of Some Heavy Metals for the Growth of Norway Spruce. Water, Air and Soil Pollut. 57-58:535-543.

Lantzy, R.J. and Mackenzie, J.L. (1979) Atmospheric Trace Metals: Global Cycles and Assessment of Man's Input. Geochim. Cosmochim. Acta. 43, pp. 511-25.

Lathrop, R.C., Rasmussen, P.W. and Knauer, D.R. (1991) Mercury Concentrations in Walleyes from Wisconsin (US) Lakes. Water, Air and Soil Pollut. 56:295-307.

Lee, Y-H. and Iverfeldt, Å. (1991) Measurement of Methylmercury and Mercury in Run-off, Lake and Rain Water. Water, Air and Soil Pollut. 56:309-321.

Lee, Y-H., Iverfeldt, Å. and Borg, G.C. (1994) Fluxes and Turnover of Methylmercury/Mercury Pools in Forest Soil. In: Watras, C.J. and Huckabee, J.W. (eds.), Mercury Pollution: Integration and Synthesis. Boca Raton, Florida: Lewis Publishers.

Lindquist, B., Jernelöv, A., Johansson, K. and Rodhe, H. (1984) Mercury in the Swedish Environment, Global and Local Sources. SNV PM 1816, Swedish Environment Protection Agency, S-171 85. Solna, Sweden.

Lindquist, O. and Rodhe, H. (1985) Atmospheric Mercury - A Review. Tellus 37B:136-159.

Lindqvist, O., Johansson, K., Aastrup, M., Andersson, A., Bringmark, L., Hovsenius, L., Iverfeldt, Å., Meili, M. and Timm, B. (1991) Mercury in the Swedish Environment - Recent Research on Causes, Consequences and Corrective Methods. Water, Air and Soil Pollut. 55.

Lockeretz (1974) Water, Air and Soil Pollut. Vol. 3, pp. 179-93.

Madsen, P.P. and Larsen, B. (1986) Accumulation of Mud Sediments and Trace Metals in the Kattegat and the Belt Sea. Marine Pollution Laboratory, Denmark, Rep. Mar. Pollut. Lab. 10, 54 pp.

Malm, O., Pfeiffer, W.C., Souza, C.M. and Reuther, R. (1990) Mercury Pollution Due to Gold Mining in the Madeira River Basin, Brazil. Ambio 19:11-25.

Maxson, P.A., Vonkeman, G.H., Brown, N., Stonneehouse, J., Thorntonne, I. and Kazantzis (1991) Mercury. Rational Paths through Uncharted Territory. Report prepared for the Commission of the European Communities DG XI.

Meij, R. (1991) The Fate of Mercury in Coal-fired Power Plants and the Influence of Wet Flue-gas Desulphurisation. Water, Air and Soil Poll. 56:21-33.

Meili, M. (1991) The Coupling of Mercury and Organic Matter in the Biogeochemical Cycle - Towards a Mechanistic Model for the Boreal Forest Zone. Water, Air and Soil Poll. 56: 333-347.

Metallgesellschaft (1992) Metallstatistik 1981-1991. Frankfurt am Main.

Michigan Environmental Science Board (1993) Mercury in Michigan's Environment: Environmental and Human Health Concerns (A Science Report to Govenor John Engler).

Minerals Yearbook (1972) Metals and Minerals. 1. US Bureau of Mines.

Minerals Yearbook (1986) Metals and Minerals. 1. US Bureau of Mines.

Minerals Yearbook (1989) Mercury. 1, 705-708. US Bureau of Mines.

Minerals Yearbook (1990) US Bureau of Mines.

Nater, E.A. and Grigal, D.F. (1992) Regional Trends in Mercury Distribution Across the Great Lakes States, North Central USA. Nature 58:139-141.

NEMA (1992a) The Management of Spent Electric Lamps Containing Mercury. National Electrical Manufacturers Association. October 1992.

NIOSH (1990) NIOSH pocket guide to chemical hazards. Washington, D.C.: US Department of Health and Human Services, Center for Disease Control, National Institute for Occupational Safety and Health, Division of Standard Development and Technology Transfer. NIOSH publication number 90-117, as referenced in ATSDR 1992.

Nordic Council of Ministers (1992) Assessment of Possibilities for Reducing the Use of Mercury – Summary of Experience from the Nordic Countries. 598.

Nriagu, J.O. (1979) The Biogeochemistry of Mercury in the Environment. Elsevier.

Nriagu, J.O. (1989) A Global Assessment of Natural Sources of Atmospheric Trace Metals. Nature 338:47-49.

Nriagu, J.O. and Pacyna, J.M. (1988) Quantitative Assessment of Worldwide Contamination of Air, Water and Soils by Trace Metals. Nature 333:134-139.

NTP (1993) Toxicology and Carcinogenesis Studies of Mercuric Chloride in F344 Rats and $B6C3F_1$ Mice. National Toxicology Program Technical Report No. 408.

OECD (1985) Measures to Reduce all Man-made Emissions of Mercury to the Environment. 1982 Information Exchange on Mercury - Summary Report. Paris.

OSHA (1989a) Toxic and Hazardous Substances. US Department of Labor. Occupational Safety and Health Administration. Code of Federal Regulations 29 CFR 1910.1000.

OSHA (1989b) Air Contaminants; Final Rule. US Department of Labor. Occupational Safety and Health Administration. Code of Federal Regulations Vol. 29, Part 1910.

OSHA (1993) Occupational Safety and Health Administration. Federal Register 58(124): 35338.

Pratt, G.C. (1990) Temporal Trends of Mercury Contamination in Fish and Sediment. Paper presented at the International Conference on Mercury as an Environmental Pollutant, Gävle, Sweden, June 11-13, 1990.

Rasmussen, P.E. (1993) The Environmental Significance of Geological Sources of Mercury: A Precambrian Shield Watershed Study. Thesis, University of Waterloo, Ontario, Canada.

Rundgren, S., Rühling Å., Schlüter, K. and Tyler, G. (1992) Mercury in Soil – Distribution, Speciation and Biological Effects. Nordic Council of Ministers. Nord 1992:3, 89 pp.

Sabbioni, E., Goetz, A., Springer A. and Pietra, R. (1983) Trace Metals from Coal-fired Power Plants: Derivation of an Average Data Base for Assessment Studies of the Situation in the European Communities. Science Total Environ. 29:213-227.

Salmi, M. (1967) Peat in Prospecting: Applications in Finland. In: Kvalheim, A. (ed.), Geochemical Prospecting in Fennoscandia. New York: Interscience, pp. 113-26.

Schintu, M., Kauri, T. and Kudo, A. (1989) Inorganic and Methyl Mercury in Inland Waters. Wat. Res. 6:699-704.

Second International Conference on the Protection of the North Sea (1987) Quality Status of the North Sea – Summary. The Department of the Environment, London.

Semb, A. and Pacyna, J.M. (1988) Toxic Trace Elements and Chlorinated Hydrocarbons: Sources, Atmospheric Transport and Deposition. Nordic Council of Ministers. Nord 1988:74, 96 pp.

Schroeder, W. H., Munthe, J. and Lindqvist, O. (1989) Cycling of Mercury Between Water, Air and Soil Compartments of the Environment. Water, Air and Soil Pollution 48:337-347.

Schuurs, A.H.B. and Davidson, C.L. (1993) Kwik, draft report.

Slemr, F. and Langer, E. (1992) Increase in Global Atmospheric Concentrations of Mercury from Measurements Over the Atlantic Ocean. Nature 355:434-437.

Slemr, F., Schuster, G. and Seiler, W. (1985) Distribution, Speciation and Budget of Atmospheric Mercury. J. Atmospheric Chem. 3:407-434.

Sorensen, J.A, Gary, E.G., Schmidt, K.W. and Rapp, R.R. (1994) Regional Patterns of Mercury and Major Ion Deposition in the Upper Midwest, USA. In: Watras, C.J. and Huckabee. J.W. (eds.), Mercury Pollution: Integration and Synthesis. Boca Raton, Florida: Lewis Publishers.

SPEED (1993) Coppoolse, J., van Bentum, F., Schwartz, M., et al. Zware Metalen in Oppervalaktewater bronnen en maatregelen. Samenverkings Project Effectieve Emissiereduktie Diffuse bronnen (SPEED). The Netherlands.

Steinnes, E., Andersson, E.M. and Jakobsen, E.B. (1993) Atmospheric Deposition of Mercury in Norway. In: Conference Proceedings (Allan, R.J and Nriagu, J.O., eds.), International Conference: Heavy Metals in the Environment, Vol. 1:70-73.

Stepanov, I.I. and Vil d'Yayev (1984) The Sources of Mercury Vapor. Geokhimiya 3:437-439.

Swain, E.B. and Helwig, D.D. (1989) Mercury in Fish from Northeastern Minnesota Lakes: Historical Trends, Environmental Correlates, and Potential Sources. J. Minnesota Acad. Sci. 55:103-109.

Taylor, S.R. (1964) Geochim. Cosmochim. Acta 28:1273-85.

Telzrow, Terry (1992) Eveready Battery Company. Presentation at US EPA Household Hazardous Waste Management Conference. December 11, 1992.

Third International Conference on the Protection of the North Sea (1990) Ministerial Declaration of the Third International Conference on the Protection of the North Sea. The Hague. March 7 and 8, 1990.

Toverud, Ö. (1977) Chemical and Mineralogical Aspects of Some Geochemical Anomalies in Glacial Drift and Peat. Sveriges Geologiska undersøkning, C729.

Turner, M.D., Marsh, D.O., Smith, J.C., Clarkson, T.W., Inglis, J.B., Rubino, E.C., Chiriboga, J. and Chiriboga, C.C. (1980) Methylmercury in Populations Eating Large Quantities of Marine Fish. Clin. Res. 35:367-378.

Tyler, G. (1992) Critical Concentrations of Heavy Metals in the Mor Horizon of Swedish Forests. Swedish Environm. Prot. Agency. Report 4078.

US Bureau of Mines (1986) Minerals Yearbook 1986, Volume 1: Metals and Minerals, Mercury, pp. 659-665.

US Bureau of Mines (1991) Mineral Industry Surveys, Mercury in 1991.

US Department of Commerce (1978) Report on the Chance of US Seafood Consumers Exceeding the Current Recommended Acceptable Daily Intake for Mercury and on Recommended Controls. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C., 1-198.

US Department of Commerce (1993) Comments on OECD Co-operative Risk Reduction Activities for Certain Dangerous Chemicals: Mercury (Draft Status Report). Letter of 22 December 1993 to Jim Darr, US EPA.

US EPA (1972) US Environmental Protection Agency. Pesticides Registration Notice No. 72-2. April 22, 1972.

US EPA (1976a) US Environmental Protection Agency. Federal Register 41:16497. April 19, 1976.

US EPA (1976b) US Environmental Protection Agency. Federal Register 41:26742. June 29, 1976.

US EPA (1976c) US Environmental Protection Agency. Federal Register 41:36068. August 26, 1976.

US EPA (1986) Quality criteria for water. US Environmental Protection Agency. US EPA 440/5-86-001, as referenced in ATSDR 1992.

US EPA (1990a) US Environmental Protection Agency. Federal Register 55(126):13756. June 29, 1990.

US EPA (1990b) US Environmental Protection Agency. Federal Register 55(177):37541. September 12, 1990.

US EPA (1991a) Characterization of products containing mercury in municipal solid waste in the United States 1970 to 1990. US Environmental Protection Agency, Municipal Solid Waste Program, Office of Solid Waste. Prepared by Franklin and Associates. November 1991.

US EPA (1991b) US Environmental Protection Agency. Federal Register 56(132):31404. July 10, 1991.

US EPA (1992a) US EPA’s 33/50 Program Second Annual Progress Report, Reducing Risks through Voluntary Action. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, TS-792A. February 1992.

US EPA (1992b) Green Lights Update, December 1992. US Environmental Protection Agency, Office of Air and Radiation. 6202J. US EPA 430-N-92-004, pp. 12-13.

US EPA (1993a) US Environmental Protection Agency. Federal Register 58(32):9247.

US EPA (1993b) EPA’s 33/50 Program Fourth Progress Update Report, Reducing Risks through Voluntary Action. US Environmental Protection Agency, Office of Pollution Prevention and Toxics. September 1993.

US EPA (1993c) Characterisation of Products Containing Mercury in Municipal Solid Waste in the United States 1970 to 2000. US Environmental Protection Agency, OSW# US EPA530-R-92-013. September 1993.

US EPA (1994) US Environmental Protection Agency. Federal Register 59(143):38288.

Vandal, G.M., Fitzgerald, W.F., Boutron, C.F. and Candelone, J.-P. (1993) Variations in Mercury Deposition to Antarctica Over the Past 34,000 Years. Nature 362:621-623.

Varekamp, J.C. and Buseck, P.R. (1986) Global Mercury Flux from Volcanic and Geothermal Sources. Applied Geochemistry 1:65-73.

Varshal, G.M., Sobolev, G.A., Barsukov, V.L., Koltsov, A.V., Kostin, B.I., Kudinova, T.F., Stakheyev, Yu.,I. and Tretyakova, S.P. (1985) Separation of Volatile Components from Rocks under Mechanical Loadings as the Source of Hydrogeochemical Anomalies Preceding Earthquakes. Pure and Applied Geophysics 122:463-477.

Verdon, R., Brouard, D., Demers, C., Lalumiere, R., Laperle, M. and Shetagne, R. (1991) Mercury Evolution (1978-1988) in Fishes of the la Grande Hydroelectric Complex, Quebec, Canada. Water, Air and Soil Poll. 56:405-417.

Weiss, H.V., Kiode, M. and Goldberg, E.D. (1971) Mercury in the Greenland Ice Sheet. Evidence of recent Input by Man. Science 174:692-694.

WGMF (1980) Report on Mercury in Fish and Fish Products. Canberra Working Group on Mercury in Fish, Department of Primary Industry, p. 371.

WHO (1976) Mercury. Environmental Health Criteria 1. Geneva.

WHO (1980) Recommended Health-based Limits in Occupational Exposure to Heavy Metals. Report of WHO Study Group, World Health Organization, WHO Technical Report Series 647. Geneva.

WHO (1989) Mercury – Environmental Aspects. Environmental Health Criteria 86. Geneva.

WHO (1990) Methylmercury. Environmental Health Criteria 101. Geneva.

WHO (1991) Inorganic Mercury. Environmental Health Criteria 118. Geneva.