Risks to Health and the Environment Related to the Use of Mercury Products

Final Report

prepared for

The European Commission, DG Enterprise

by

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EXECUTIVE SUMMARY

Overview

Mercury and its compounds are hazardous materials which may pose risks to people and to the environment. This report presents an assessment of the risks associated with the use of mercury in a range of products.

The key requirements of the study were:

- *to identify usage of mercury in dental amalgam, batteries, measuring instruments (such as thermometers and manometers), lighting, other electrical components and other lesser uses;*
- *to review data used to evaluate the toxicity of mercury and mercury compounds to humans and to the environment;*
- *to derive predicted environmental concentrations (PECs) associated with use of the products under consideration and compare with those associated with other sources of mercury; and*
- *to characterise the associated risks.*

Mercury Use in Products under Study

The use of mercury in the main product groups - dental amalgam, batteries, discharge lamps, measuring (and control) equipment and electrical control and switching equipment has been characterised. Although research and consultation has enabled aspects of the various lifecycles to be quantified, comprehensive data were not obtained for all areas with particular reference to the last two product groups (measuring (and control) equipment and electrical control and switching).

The mercury used in the products within the EU (and the three accession countries) comes: from primary production (in Spain); as a by-product of non-ferrous metal production; from a mercury recycling plant; or as an import (usually within the product, as in the case of thermometers). Some data on these production routes (and associated emissions) were obtained but determining the precise scale and extent of the mercury 'business' proved difficult. However, it would appear that the recovery of mercury from decommissioned chlor-alkali facilities is rapidly become the major source of mercury within the EU.

Overall, there is clear evidence that the use of mercury in batteries and lamps has significantly reduced in recent years. There has also been a decline in the use of dental amalgam and, as importantly, there has been a significant increase in the use of mercury recovery devices (separators) in dental surgeries. Although there has been a reduction in the use of mercury thermometers and sphygmomanometers (for measuring blood pressure), it has been difficult to estimate the overall use of mercury within this sector. Similarly, whilst there has been a move away from the extensive use of mercury tilt switches in domestic products (including cars, white goods, etc.), the extent of mercury use in other applications within this sector has been difficult to determine.

It is estimated that the current usage of mercury in these product groups is about 120 tonnes per year (60% of which is associated with dental amalgam) in the EU with, perhaps, a further 50 tonnes per year used in the three accession countries under study (Czech Republic, Poland and Slovenia). It is estimated that the emissions to the environment associated with the production of mercury used in these products, product manufacture and product use is less than 25 tonnes per year.

Mercury Use in Other Products

Mercury is used in numerous diverse products and applications, ranging from its use in lighthouses (some lights revolve in a bath of mercury) to recoil suppression systems in rifles. However, these account for a relatively low consumption with one notable exception. It would appear that, perhaps, 50 tonnes per year of mercury is used in the manufacture (within the EU) of skin lightening creams and other cosmetic products, most of which are exported to, and consumed in, Africa. It should be noted that the marketing of mercury containing cosmetic products (with the exception of trace amounts in eye products) is not permitted within the EU.

Other Sources of Mercury

Large quantities (thousands of tonnes) of mercury are used in chlor-alkali plants throughout the world. Most EU countries have such plants (as does the Czech Republic and Poland) and current estimates of mercury consumption (within the EU) are of the order of 150 tonnes per year. As indicated above, the planned phase-out of mercury usage in chlor-alkali plants will lead to a substantial flow of recovered mercury onto the market over the next 20 years (perhaps 650 tonnes per year within Europe). The associated emissions (primarily to atmosphere) are estimated to be less than 10 tonnes per year although significant amounts of mercury are unaccounted for.

Although mercury is a trace constituent of fossil fuels, fossil fuel consumption within the EU may release in the order of a further 150 tonnes per year into the environment which is comparable to a recent estimate that total anthropogenic emissions from the EU (and the three accession countries) are of the order of 160 tonnes per year.

Apart from anthropogenic sources of mercury, there are 'natural' releases from forest fires, volcanoes and 'evaporation' from the oceans. Within the EU, recent estimates suggest that 'natural' emissions within the EU may amount to 200 tonnes per year.

Predicting Environmental Concentrations

The behaviour of mercury in the environment is complex. Most releases are in elemental form to atmosphere which is then slowly oxidised to bivalent mercury (inorganic mercury). The inorganic mercury enters the terrestrial and aquatic environments through deposition. A portion of the inorganic mercury is methylated (particularly within sediments) to produce methyl mercury (organic mercury) which enters the water column. There is a general consensus that the key concern is organic mercury, which is highly toxic and bio-accumulates - particularly in fish.

For this study, the EUSES model was used (with some modifications) to predict mercury concentrations in the three main environmental compartments (air, terrestrial and aquatic). In essence, the model was run twice:

Run 1: 100% of emissions considered to be as elemental mercury in order to obtain predictions for the atmospheric compartment; and

Run 2: 100% of emissions considered to be as inorganic mercury (mercuric chloride) to obtain predictions for the terrestrial and aquatic compartments.

The key inputs to the EUSES model were emissions (derived from the lifecycle analysis for the product groups) and toxicity data for humans and the environment. It was assumed, as a worst case, that the organic mercury concentrations would be 10% of the inorganic mercury concentrations.

The PECs (predicted environmental concentrations) for each compartment showed that the products' use, their manufacture and the production of the associated mercury contributed a percent to typical existing concentrations at continental level. At a regional level, the contribution was higher.

At a 'local' level (i.e. close to production facilities), significant air concentrations (elemental mercury) were predicted close to the primary production site in Spain. Otherwise, local values were very close to the regional values.

Risks Associated with Products under Study

Typical intakes of mercury are of the order of 10 µg/day. About 75% is elemental and inorganic mercury, most of which is associated with the inhalation of vapours from dental amalgam used in fillings. The remaining 25% is organic mercury (primarily methyl mercury in fish and fish products). For this study, reference doses of 2.0 and 0.1 µg per kg of bodyweight per day have been used as 'safe' levels for inorganic (including elemental) and organic mercury respectively.

Risks to humans associated with exposure to mercury in the environment are considered against a 'margin of safety' (MOS) value which is derived by dividing the reference dose by the appropriate predicted environmental concentration (PEC).

At a regional level, MOS values associated with elemental and inorganic mercury were found to be in excess of 100 (i.e. mercury intake is more than 100 times below 'safe' levels) whilst the MOS value for organic mercury was 18.

At a local level, MOS values associated with elemental mercury and inorganic mercury were generally found to be in excess of 100 although the higher atmospheric emissions close to the primary production site in Spain led to an MOS value of 6.5 and that for lamp production was found to be 55. For organic mercury, the local MOS values were essentially the same as the regional value (18).

In terms of risks to the environment, the criterion of importance is the ratio of the predicted environmental concentration (PEC) to the predicted no-effect concentration (PNEC). PEC/PNEC ratios of greater than unity are indicators that there may be a risk of concern.

PEC/PNEC ratios were derived for water, sediment, soil and (local) secondary poisoning (poisoning through the predatory food chain). The key findings may be summarised as follows:

- *for water, the PEC/PNEC ratios for inorganic and organic mercury were significantly less than unity;*
- *for sediment, the PEC/PNEC ratios were significantly less than unity for inorganic mercury whilst those for organic mercury were in the range 0.2 - 0.4;*
- *for soil, the PEC/PNEC ratios for inorganic mercury were about 0.2; and*
- *for secondary poisoning, the PEC/PNEC ratios were significantly less than unity for the terrestrial food chain (inorganic mercury) whilst those for the aquatic food chain (organic mercury) approached unity (0.9).*

Recommendations

Overall, using the TGD/EUSES approach (with modifications), it would appear that there are unlikely to be significant risks to the environment associated with the mercury containing products under study - with particular reference to dental amalgam, batteries, lamps, measuring and electrical equipment. Of the products under study, the key contributor is dental amalgam, which accounts for over half of the mercury used.

The modelling results suggest that the risks are primarily associated with organic mercury. However, given the complexity of the behaviour of mercury in the environment, the modelling has necessitated simplifying assumptions which clearly introduces a degree of uncertainty. Furthermore, changes to some critical parameters (such as partition coefficients) can make significant changes to the results.

Nevertheless, in accordance with the TGD, the results suggest a Conclusion (ii) which states that there is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already. To this, could be added or are already planned, since there are a number of Directives (Water Framework Directive, RoHS Directive, ELV Directive, etc.) which will lead to further controls on the usage and emissions of mercury.

However, it is recognised that there is widespread concern over the presence of mercury in the environment and a desire to further limit the potential impacts of mercury usage. Of the estimated 160 tonnes per year of mercury emitted to the environment from anthropogenic sources in the EU and the three accession countries, the products under study account for less than 25 tonnes per year. There may, however, be areas where further reductions could be achieved in usage and/or associated emissions across the range of products examined here. Such reductions should be proportional to the relative emissions within the context of the overall anthropogenic use of mercury and the associated emissions.

In relation to the products under study, dental amalgam is the largest use with over 10 tonnes per year of mercury being emitted to the environment. The dominant source of emissions is releases from crematoria and this may be an area for further investigation. Measuring and control equipment would also appear to be a key source with emissions of 8.5 tonnes per year

- primarily to the atmosphere from landfills. Within this sector, there may be areas where usage and/or emissions could be reduced. The other three products areas (batteries, lighting and electrical equipment) have significantly lower usage and emissions.

More generally, it is worth noting that the production of skin lightening creams involves the consumption of mercury in greater quantities than those used for measuring and control equipment - although this may be an area where more enforcement rather than more controls is required.

It is important to stress that any proposed controls would need a further investigation of the advantages and drawbacks under the requirements of the Marketing and Use Directive (76/769/EEC).

Finally, it is recommended that consideration should be given to classification and labelling under Directive 67/548/EEC based upon the developmental toxicity of methyl mercury and, perhaps, of other organic mercury compounds.

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1. INTRODUCTION

1.1 Overview

Mercury and its compounds are hazardous materials which may pose risks to people and to the environment. This report presents an assessment of the risks associated with the use of mercury in a range of products.

Specifically, the key elements of the study were specified in the Technical Specifications (reproduced in Annex 1) as follows:

- to identify the usage of mercury in dental amalgam, batteries, measuring instruments (such as thermometers and manometers), lighting, other electrical equipment and other lesser uses;
- to review data used to evaluate the toxicity of mercury and mercury compounds to humans and to the environment;
- to derive predicted environmental concentrations (PECs) associated with the use of the products under consideration;
- to characterise the associated risks; and
- to compare these with the risks associated with other sources of mercury.

1.2 Background

European legislation has significantly reduced the use of mercury in a range of products in recent years. In addition, there is a number of EU Directives which regulate mercury in relation to health and safety, water quality, pesticides, foodstuffs, atmospheric emissions and waste disposal. Directives of interest include:

- Council Directive 82/176/EEC which laid down emission limits values and quality objectives for mercury discharges by the chlor-alkali electrolysis industry;
- Council Directive 84/156/EEC which laid down limit values and quality objectives for mercury discharges by sectors other than the chlor-alkali industry;
- Council Directive 89/677/EEC which restricted the use of mercury in preservative paints used for anti-fouling and for wood, textiles and yarn;
- Council Directive 91/157/EEC which introduced requirements for the safe collection/disposal of spent batteries and accumulators;
- Council Directive 91/188/EEC which prohibited the marketing and use of mercury compounds in plant protection products;
- Commission Directive 98/101/EC which prohibits marketing of batteries with more than 0.0005% mercury by weight (more than 2% for button cells);
- Council Directive 2000/53/EC which prohibits use of mercury in new road vehicles from 2003;

- Directive 2000/60/EC of the European Parliament and Council which established the framework for, *inter alia*, regulating discharges to water (the Water Framework Directive); and
- Proposed Directive COM (2000) 347 which, if adopted, will impose restrictions on the use of certain hazardous substances (including mercury) in electrical and electronic equipment (the RoHS Directive).

It should be noted that under the Water Framework Directive, mercury and its compounds have been designated[1] as 'priority hazardous substances' (based, in part, upon the recommendations of international fora - as outlined below). As such, this designation requires, in principle, the "cessation or phasing out of discharges, emissions and losses within 20 years". However, as mercury is naturally occurring, this requirement is modified as follows:

> *"... cessation of discharges, emissions and losses into water of those priority hazardous substances which derive from human activities."*
> (Decision 2455/2001/EC, para 4)

In addition, some member countries have moved to implement a more comprehensive phase-out of mercury use. Examples of relevant national legislation include:

- *Denmark:* **Prohibition of Sale and Export of Mercury and Mercury-Containing Products** (Statutory Order 692 dated September 1998), which provides for a gradual phase-out of products containing more than 50 ppm mercury (i.e. 0.005% by wt);
- *Sweden:* **A Chemical Strategy for a Non-Toxic Environment** (Bill 2000/01:65), which is seeking a complete phase-out of mercury in new products by 2003; and
- *Netherlands*: **Decree on Products Containing Mercury** (dated 9 September 1998) which is also seeking a ban on mercury-containing equipment by 2003 - although there are exemptions for a range of specified products.

One of the aims of this study is to inform discussions on further possible restrictions on mercury through the provision of up to date and relevant information from across the EU (as well as from three accession countries - Poland, Czech Republic and Slovenia).

Mercury and its compounds are also the subject of other international initiatives which will need to be taken into account. These include:

- the **1998 Aarhus Protocol on Heavy Metals**[2] relating to cadmium, lead and mercury. This UN Economic Commission for Europe (UNECE) Protocol has been signed up to by 36 countries (including all EU states and the three accession countries of interest to this study). Each party which has signed the protocol is

[1] Decision 2455/2001/EC of the European Parliament and Council dated 20 November 2001.

[2] Full text and associated information available from www.unece.org/env.

required to reduce their total annual mercury emissions to below 1990 levels with the use of best available techniques and the setting of limit values for emissions. With regard to mercury products in particular, the Protocol requires that the contracting parties should apply control measures on the content of Hg in alkaline-manganese batteries (0.05% for batteries used in extreme conditions and 0.025% for all other alkaline-manganese cells) and should also consider applying product management measures including substitution of products, reduction or substitution of mercury in products, appropriate labelling for safe use and disposal of products and use of economic instruments and voluntary agreements. Precautionary measures should be considered for mercury-containing measuring and electrical control equipment, fluorescent lamps, dental amalgam, pesticides, paints, and batteries;

- **HELCOM**[3] (the Helsinki Commission or, more formally, the Baltic Marine Environment Protection Commission) has an active interest in limiting mercury emissions to the Baltic Sea;
- similarly, **OSPAR**[4] (the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic) has an active interest in limiting mercury emissions to the Atlantic Ocean; and
- **UNEP** (the United Nations Environment Programme) is currently undertaking a Global Mercury Assessment (as discussed further below).

1.3 Sources of Information

The starting point for the study was two earlier studies undertaken for the Commission:

- WS Atkins (1998): **Assessment of the Risk to Health and to the Environment of Mercury Contained in Certain Products**, Final Report dated August 1998. This report focuses on the risks associated with electrical equipment, measuring instruments and lighting - but not batteries nor dental amalgam; and
- ERM (1998): **Analysis of the Advantages and Drawbacks of Restricting the Marketing and Use of Mercury in Certain Products**, Final Report dated December 1998. This report focuses on the potential for substitution of mercury in dental amalgam, electrical equipment, measuring instruments and lighting - but not batteries.

In order to extend and refine the data presented in these reports, there has been an extensive review of literature and other sources of information as well as consultation with a range of interested parties. Particular attention has been given to recent submissions to the Global Mercury Assessment being co-ordinated by UNEP. Submissions from EU Governments and others can be inspected (and downloaded)

[3] The contracting parties are Denmark, Estonia, European Commission, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. Further information is available from www.helcom.fi.

[4] The contracting parties are Belgium, Denmark, European Commission, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK. Further information is available from www.ospar.org

from www.chem.unep.ch/mercury. This website is a valuable resource containing current information from a wide range of countries and organisations, as well as a large collection of relevant reports and other documents. UNEP has prepared an initial draft report on the submissions received (UNEP, 2002).

Further information on the changing usage of mercury-containing products has been sought from the *Europroms* database[5]. The focus of this data-base is on trade (i.e. imports and exports) with EU members states, both 'intra EU' and 'extra EU'. However, these data do not provide a direct route to reliably estimate usage by individual member states (nor, indeed, by the EU-15 as a whole). Against this background, the *Europroms* data have been used to illustrate trends in usage rather than as a primary source of usage data.

1.4 Structure of the Report

An overview of the properties of mercury and its compounds is presented in Section 2 with a detailed review of mercury usage in products presented in Section 3.

The complex behaviour of mercury in the environment together with an overview of typical concentrations in the EU environment are presented in Section 4.

The predicted environmental concentrations (PECs) associated with the usage of mercury in products are presented in Section 5. Section 6 provides a review of the toxicity of mercury and its compounds to people and to the environment.

Combining the results from Sections 5 and 6 enables an estimate to be made as to whether there are significant risks associated with the products under consideration and this is presented in Section 7. Section 8 summarises the overall findings.

[5] Eurostat (2001): **Europroms - European Production and Market Statistics**, data-base available from the European Commission which includes comprehensive data on products on a quarterly and annual basis up until 1999.

2. GENERAL SUBSTANCE INFORMATION

2.1 Physico-chemical Properties of Mercury and Mercury Compounds

Physico-chemical properties and classification numbers of mercury and mercury compounds of relevance are summarised in Table 2.1.

Table 2.1: Main Physico-chemical Properties and Chemical Registration Numbers of Mercury and Mercury Compounds

Substance	Formula	CAS No. (EC No.)	Molecular Weight	Melting point ^{o}C	Boiling point ^{o}C	Solubility in water
Mercury	Hg	7439-97-6 (231-106-7)	201	-39	357	0.06 mgl^{-1}
Mercuric chloride	$HgCl_2$	7487-94-7 (231-299-8)	271	276	302	69,000 mgl^{-1}
Mercuric sulphide	HgS	1344-48-5 (215-696-3)	233	sublimes at 400	n/a	insoluble
Mercuric oxide	HgO	21908-53-2 (244-654-7)	217	500	n/a	50 mgl^{-1}
Methyl mercury *	CH_3Hg^+	22967-92-6	216			
Methyl mercuric chloride	CH_3Hg Cl	115-09-3 (204-064-2)	251	170	n/a	near insoluble
Dimethyl mercury	C_2H_6Hg	593-74-8 (209-805-3)	231	-43	92	9,000 mgl^{-1}

Sources: Croner (1999): Substances Hazardous to the Environment, London, Croner Publications; ChemFinder Internet site, www.chemfinder.com; and Sigma-Aldrich Material Safety Data Sheets.

** Note that methyl mercury is an ion rather than a chemical compound and, as such, does not exist in a 'free' state.*

2.2 Environmental Classification and Labelling

Commission Directive 98/98/EC of December 1998 (which adapted **Council Directive 67/548/EEC on the Classification, Packaging and Labelling of Dangerous Substances** to technical progress for the 25th time) introduced environmental classification and labelling for mercury and its compounds as shown in Table 2.2.

Table 2.2: Classification of Mercury Compounds for Environmental Effects

Substance	Classification	Risk Phrases
Mercury	N: Dangerous to the environment	R 50/53: Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
Inorganic mercury compounds in general (except mercuric sulphide)		
Organic mercury compounds in general		

2.3 Human Health Classification and Labelling

Mercury and mercury compounds of interest for this study have also been given classifications under Directive 67/548/EEC for human health and safety. These are summarised in Table 2.3.

Table 2.3: Classification of Mercury Compounds for Human Health and Safety

Substance	Classification	Risk Phrases	Safety Phrases
Mercury	Toxic (T)	R 23 R 33	S (1/2); S 7; S 45; S 60; S 61
Mercuric chloride	Very Toxic (T+) Corrosive (C) Toxic (T)	R 28 R 34 R 48/24/25	S (1/2); S 36/37/39; S 45; S 60; S 61
Mercuric oxide (and inorganic mercury compounds in general - but with some exceptions)	Very Toxic (T+)	R 26/27/28 R 33	S (1/2); S 13; S 28; S 45; S 60; S 61
Organic mercury compounds in general	Very Toxic (T+)	R 26/27/28 R 33	S (1/2); S 13; S 28; S 36; S 45; S 60; S61

Sources: The National Chemical Emergency Centre UK Internet site, www.the-ncec.com
International Labour Organisation, International Chemical Safety Cards

Note: Classifications confirmed on www.kemi.se/nclass which maintains data on classification on behalf of the European Chemical Bureau (ecb.jrc.it/classification_labelling). Latest classification for mercury and its compounds is based on 25th ATP (Directive 98/98/EC).

Risk Phrases:

R 23	Toxic by inhalation;
R 26/27/28	Very toxic by inhalation, in contact with skin and if swallowed;
R 28	Very toxic if swallowed;
R 33	Danger of cumulative effects;
R 34	Causes burns; and
R 48/24/25	Toxic: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed.

Safety Phrases:

S 1/2	Keep locked up and out of reach of children;
S 7	Keep container tightly closed;
S 13	Keep away from food, drink and animal feeding stuffs;
S 28	After contact with skin, wash immediately with plenty of water;
S 36	Wear suitable protective clothing;
S 36/37/39	Wear suitable protective clothing, eye/face protection and gloves;
S 45	In case of accident or if you feel unwell, seek medical advice immediately (show label where possible);
S 60	This material and its container must be disposed of as hazardous waste; and
S 61	Avoid release to the environment. Refer to special instructions/safety data sheet.

It should be noted that risk phrases associated with substances toxic to reproduction are not currently applied to mercury and its compounds. Such phrases include:

R 60	May impair fertility;
R 61	May cause harm to the unborn child;
R 62	Possible risk of impaired fertility; and
R 63	Possible risk of harm to the unborn child.

As explored in more detail in Section 6.3, developmental toxicity effects are considered to occur with exposure to low levels of methyl mercury. On this basis, and with reference to the guidance provided by the 28th ATP[6], it would appear that methyl mercury (at least) could be designated a Category 1 substance (due to observed developmental toxicity in humans) and require the risk phrase R61. For other organic mercury compounds, it may be the case that a Category 3 designation ('substances which cause concern for humans owing to possible developmental toxic effects') and an associated R63 risk phrase is more appropriate.

[6] Commission Directive 2001/59/EC of August 2001 (which adapted **Council Directive 67/548/EEC on the Classification, Packaging and Labelling of Dangerous Substances** to technical progress for the 28th time).

3. GENERAL INFORMATION ON MERCURY USAGE

3.1 Overview of Mercury Production and Usage

3.1.1 Introduction

There are three sources of mercury for use in the products of interest:

- extraction of mercury from mercury ore;
- production of mercury as a by-product of non-ferrous metals processing; and
- recovered mercury from waste streams and other sources.

The general picture has changed dramatically in the last few years with the commitment of the chlor-alkali industry to phase-out the use of mercury cells in European chlorine production. This will lead to the recovery and potential re-use of perhaps 15,000t of mercury over the next 20 years (ERM, 2000).

3.1.2 Mined (Primary) Production

Mercury is a naturally occurring metallic element, found in rocks, soils and sediments, which comprises part of the earth's crust at levels of approximately 0.5 ppm. It is commonly found as the red sulphide ore, cinnabar (HgS), which provides the main source of mined mercury.

The worldwide primary production of mercury peaked in the early 1970s at about 10,000 tonnes per annum. Since then, there has been a steady decline to perhaps 1,650 tonnes in 2000 (USGS, 2001) as presented in Table 3.1. Estimated world *resources* are about 600,000 tonnes - mainly in Kyrgyzstan, Russia, Slovenia, Spain and Ukraine. World *reserves* (i.e. currently accessible) are estimated to be 240,000 tonnes (see Table 3.1). The decline in production has been accompanied by a dramatic decline in price from around €1,000 per flask[7] in the late 1960s to less than €100 per flask in 1991, compared with a current price of about €180 per flask (i.e. about €5 per kg).

Within the EU, Minas de Almadén y Arrayanes SA (MAYASA) of Spain is the main producer (accounting, historically, for more than 30% of the world's mined production) with smaller amounts being produced in Finland (as a by-product of zinc mining at Kokkola - see below) and, formerly, at the Idrija mine in Slovenia as set out in Table 3.2. Also, the cinnabar mines of Mount Amiata in Italy were a major source of mercury for many centuries but were finally closed in 1976. Of note is that nearly 75% of Spain's current sales is exported to Asia with only 15% (about 150 t/year) being used within the EU (consultation). Of the three accession countries of interest, only Slovenia is associated with the primary production of mercury.

[7] Quantities of mercury are often expressed in flasks. One flask is about 2.5 litres and weighs 34.5 kg.

Table 3.1: Mercury World Mine Production 1996-2000 (metric tonnes)				
Country	**1996**	**1998**	**2000***	**Reserves**
Algeria	368	224	240	3,000
China	510	230	200	
Finland	**88**	**54**	**45**	
Italy	0	0	0	69,000
Kyrgyzstan	584	620	550	13,000
Mexico	15	15	25	
Russia	50	50	50	
Slovakia	0	20	0	
Slovenia	**5**	**5**	**0**	
Spain	**862**	**675**	**500**	90,000
Tajikistan	45	35	40	
Ukraine	30	20	?	
USA	?	?	?	
Other	0	0	0	61,000
World Total (rounded)	**2,560**	**1,950**	**1,640**	**240,000**
** estimates (by US Geological Survey - USGS)*				
Source: USGS, 2001				

Table 3.2: Mercury Primary Production in EU and the 3ACs[1] (1996-2000) (metric tonnes)					
Country	**1996**	**1997**	**1998**	**1999**	**2000**
Spain[2]	1053	863	675	1352 (sales)	1095 (sales) 236 (mined)
Slovenia	5	5	5	closed	closed
Sources: USGS (2001) and consultation.					
Notes:					
1) 3ACs = Czech Republic, Poland and Slovenia					
2) The figures for Spain are derived from direct consultation with MAYASA and that 'sales' now include mined production, recovered mercury from the chlor-alkali industry and sales from stock. It will be noted that in 2000, the actual mined production was 236 tonnes, much lower than the 500 tonnes estimated by USGS (as presented in Table 3.1).					

3.1.3 Production from Non-Ferrous Metals Processing

Many ores contain traces of mercury and their processing (usually involving heat) generates mercury vapour which is recovered from the gas cleaning stream. Due to the large quantities of ores, even low concentrations of mercury can generate significant quantities (for example - 200,000 t/year of ore containing 0.01% mercury will produce 20 t/year). Within the EU, the overall mercury production rate is estimated to be about 350 t/year (EC, 2001), primarily associated with zinc and lead smelting/refining. Within the EU, there are 10 zinc smelters with capacities of greater than 100,000 t/year and 7 primary lead smelters/refiners with capacities of greater

than 40,000 t/year located in Belgium, France, Germany, Italy, the Netherlands, Spain and the UK. There is also extensive lead/zinc mining and processing in Poland (especially in the Tarnowskie Góry area). It is worth noting that although Ireland mines the most zinc ore in Europe, the associated processing is carried out in Finland. Of the associated mercury recovery operations, those in Finland have been regularly recorded as primary mercury production as shown in Table 3.3. However, consultation with some of the other large zinc smelters indicates much lower quantities of mercury being produced which, in some cases, is sent directly to landfill in the form of mercurous chloride (calomel).

Table 3.3: Mercury Production in Finland (1996-2000) (metric tonnes)

Country	1996	1997	1998	1999	2000
Finland	88	63	54	55	77

Sources: Finnish Ministry of Trade and Industry (www.gsf.fi/explor/finmipr9800.htm) and USGS (2001).

3.1.4 Reclaimed Mercury (Secondary Production)

Factors including moves to minimise releases of mercury to the environment have led to an increase in the recovery of mercury from waste products. By way of example, Finland has one plant recovering mercury from dental amalgam. Similarly, a mercury recycling facility in Manchester, UK[8] recovers mercury from lights, dental amalgam, button cells and thermometers and the mercury is reused in lights, barometers and other uses.

Although the overall quantity of secondary (reclaimed) mercury production (within the EU and the three accession countries) is difficult to estimate, it was, until recently, perhaps of the order of 50 t/year. However, the situation has now changed dramatically as the mercury from decommissioned chlor-alkali plants begins to enter the market. By way of example, MAYASA reports that 400t of mercury from decommissioned chlor-alkali plants were processed for re-sale in 2000. In the coming years, the chlor-alkali industry would be expected to generate about 650 t/year (i.e. 15,000 tonnes over the period 1998-2020).

3.1.5 Trade in Mercury

Recent data from *Europroms* indicate that the EU is a net exporter of mercury, as shown in Table 3.4.

Table 3.4: EU Trade in Elemental Mercury (i.e. not in products)

Year	Imports into EU	Exports from EU	Exports from Spain
1997	250t	810t	510t
1998	120t	670t	300t
1999	430t	910t	510t

Source: Europroms data

[8] See www.mercuryrecycling.co.uk

As indicated in Section 1.3, caution must be exercised in relying on data such as those presented in Table 3.4. Nevertheless, as would be expected, the export figures are dominated by those from Spain (MAYASA) although the *Europroms* values are slightly lower than those provided by MAYASA. In relation to the products under study, there are imports (into the EU) of products containing mercury (such as thermometers and batteries). However the imported quantities of liquid mercury as a 'raw' material for these products is likely to be limited[9]. In other words, the imported quantities of mercury required for the products under consideration are likely to be well below the quoted figure of 400 t/year. Possible explanations include:

- imported figures include figures for material that is re-exported (for example, in transit through the Port of Rotterdam in the Netherlands);
- some imports may be destined for mercury recovery plants; and
- some imports may be destined for use in chlor-alkali plants.

Indeed, the 'real' situation may be more complex. By way of example, the 1999 imports include over 60t destined for Spain, which according to MAYASA, were re-exported with minimal processing. Although efforts have been made to clarify other key national figures for recent imports and exports with the relevant national authorities, these have not produced any useful data.

3.1.6 Overview of Mercury Uses

Mercury is found in a wide range of products including dental amalgam, pharmaceuticals, thermometers, manometers, batteries, fungicides/pesticides, fluorescent tubes, high-pressure lights, neon lighting, thermostats (and other switch sensors) on heating/ventilation systems, industrial plant controls, electrical equipment (relays, etc.), mercury cells used in chlorine production, etc.

This study is focused on the use of mercury in certain products and excludes mercury usage in chlorine production, for pharmaceuticals and for agrochemical purposes. The main use 'types' have therefore been defined as follows:

- dental amalgam (see Section 3.2);
- batteries (see Section 3.3);
- lighting (see Section 3.4);
- measuring and control equipment (see Section 3.5);
- electrical equipment (see Section 3.6); and
- other products (see Section 3.7).

There are few estimates of the current consumption of mercury in the EU. In the mid-1990s, the usage of mercury within the above product groups was estimated as summarised in Table 3.5. Current usage (for 2000) for the EU-15 countries together with that for the three accession countries is also presented, based on the results of data collection carried out for this study.

[9] By way of example, some dental products (including sachets of mercury) are imported from suppliers located in Australia and the US.

Table 3.5: EU Mercury Consumption by Product Group (t/year)				
Product	**mid-1990s[1]**	**1996[2]**	**2000[3]**	
			EU-15	**3ACs**
Dental amalgam	not given	69	70	20
Batteries	not given	5 - 8	8	1
Lighting	21	>12	5.2	0.7
Measuring and control equipment	56	<63	28	5
Electrical equipment	28	not given	8	1
Sub-totals:	**>105**	**c150**	**119.2**	**27.7**
Other products	<2	73	c50	c5
All of the above:	**>107**	**c220**	**c170**	**c33**

Sources: 1) WS Atkins (1998); 2) Eurochlor (1999); and 3) based on information presented below where the 3ACs = Czech Republic, Poland and Slovenia.

3.2 Dental Amalgam

3.2.1 Overview

Mercury-based dental amalgam contains 40-50% mercury which is mixed with other powdered metals prior to insertion into the dental cavity. Mercury may be applied from a dispenser or from capsules (generally 400 or 600 mg). The typical filling uses 0.7 g amalgam (i.e. 350 mg mercury) and the residual mercury (and associated waste) is usually collected *in situ*.

3.2.2 Control Issues

At the outset, it is important to emphasise that measures to control the use of mercury amalgam are primarily a result of concerns over subsequent releases to the environment rather than over health risks to patients. Nevertheless, it is recognised that oral health personnel may be exposed to mercury vapour during frequent amalgam preparation and insertion with an associated low level of risk. In order to minimise such risks, dentists are provided with authoritative advice on best practice for amalgam usage[10].

At an International Level

The position of OSPAR (2000) is that the earlier PARCOM recommendation 93/2: "*equipment should be installed to separate water and amalgam to enable collection of the amalgam as from 1 January 1997*" has largely been implemented by OSPAR signatories. Reduction in mercury usage and increased use of amalgam separators is also encouraged by the Aarhus Protocol (UNECE, 1998).

At a National Level

A summary of controls at a national level is provided in Table 3.6.

Table 3.6: National Controls for Dental Amalgam

Country	Control	Source & Comment
Austria	All surgeries are provided with amalgam separators	consultation
Belgium	All surgeries in process of being provided with amalgam separators	consultation
Denmark	Being phased out under Order 692 and may only be used in molar teeth to replace worn fillings. Amalgam separators in all public health dentists	HELCOM (2001), consultation
Finland	In line with HELCOM Recommendation 6/4, waste water may only be discharged after 95% amalgam separation - Council of State Decision 112/1997. Currently, >90% surgeries have separators	Submission to UNEP (2001), HELCOM (2001) and consultation
France	As of 2000, all surgeries require separators and amalgam used must be pre-dosed (thus avoiding 'loose' mercury)	INRS (2002)

[10] See, for example, FDI World Dentist Federation (1999): **Recommendations on Dental Mercury Hygiene**, based on FDI General Assembly 1998 and available from www.fdi.org.uk.

Table 3.6: National Controls for Dental Amalgam		
Country	**Control**	**Source & Comment**
Germany	Since 1990, a minimum of 95% mercury collection required from amalgam separators which are provided in nearly all surgeries	OSPAR (1997), submission to UNEP (2001) & consultation
Greece	Separators not required	consultation
Netherlands	Since 1994, a minimum of 95% mercury collection required from amalgam separators	OSPAR (1997)
Portugal	All surgeries in process of being provided with amalgam separators (currently 20%)	consultation
Sweden	Since 1985, a minimum of 95% mercury collection required from amalgam separators. All surgeries provided with separators	OSPAR (1997)
United Kingdom	As of 1997, 25% of surgeries provided with separator. New guidance recommends wider provision to implement PARCOM recommendation 93/2	WS Atkins (1997) DEFRA (2001)
Poland	Separators not required but extracted amalgam fillings are collected and treated	consultation
Czech Republic	Separators required for new dentist chairs from January 2002. By January 2005, all surgeries must be provided with separators	consultation

3.2.3 Quantities Used

EU Wide

No estimate of mercury usage in dental amalgams is provided by WS Atkins (1998) nor by ERM (1998). Estimates for 1990 and 2000 based on the more detailed information presented below suggests that the mercury consumption in the EU in dental amalgam was likely to have been of the order of 110 t/year in 1990 which has now reduced to the order of 70 t/year with, perhaps, a further 20 t/year used in the three accession countries.

By Country

More detailed information on the use of mercury dental amalgams by country is presented in Table 3.7.

Table 3.7: Dental Amalgam Consumption by Country (t/year)			
Country	**c1990**	**c2000**	**Source & Comment**
Austria			Amalgam usage has not changed in recent years (consultation)
Belgium	3.7 (1990)		OECD (1995). Amalgam usage reduced by >25% in recent years (consultation)
Denmark	2.0 (1991) 1.8 (1992/3)	c1.0 (current)	OECD (1995), HELCOM (2001) & consultation. Amalgam usage reduced >50% amongst children in recent years
Finland	1.2 (1987)	c1.0 (1996/97) <0.2 (current)	OECD (1995), consultation. Amalgam usage reduced >50% in recent years - now very limited

Table 3.7: Dental Amalgam Consumption by Country (t/year)			
Country	**c1990**	**c2000**	**Source & Comment**
France	16.0 (1990-92)	20-25 (current)	OECD (1995), detailed report with French submission to UNEP (2001)
Germany	24.1 (1985) 29 (1993)		OECD (1995), submission to UNEP (2001) and consultation. Amalgam usage reduced 30-40% in recent years
Greece			Usage reduced by >50% in recent years (consultation)
Ireland		1.6 (1996)	CTC (1999)
Netherlands	5.5 (1989) 5.2 (1990)		OECD (1995), Slooff *et al.* (1995)
Portugal			Usage reduced by >50% in recent years (consultation)
Sweden	1.7 (1991)		OECD (1995). Amalgam usage reduced by >50% in early 1990s (submission to UNEP (2001)
United Kingdom	11.4 (1989-90)	12 (1997)	OECD (1995), WS Atkins (1997) - amalgam usage reduced by >25% in period 1992-97
EU Total	***c110***	***c70***	***RPA estimates***
Poland	*13**	*13**	Amalgam used in about 60% of fillings. Similar practice to Germany of early 1990s with no reduction (consultation)
Czech Republic	*5.8**	5.8	Amalgam usage not declining - and may even be increasing as covered by national health insurance (consultation)
*Note: * RPA estimate*			

As a first estimate, it can be seen from Table 3.7 that about 70 t/year was used by about 65% of the EU-15 population in 1990[11] giving an EU-15 total consumption of the order of 110 t/year. Consultation with dental associations (and other sources) suggests that this value has dropped significantly in most EU countries in recent years - perhaps to 70 t/year with, perhaps, a further 20 t/year used in the three accession countries.

3.2.4 Lifecycle and Emissions

Manufacture

Dental amalgam is formulated in the dental surgeries. The most common method is the use of mixing pre-packed capsules of alloy particles and mercury, although 'bulk' mercury is still used (particularly in the UK).

The mercury used in dental surgeries may have passed through several stages (and several companies) as illustrated below:

[11] Base information (such as population data) on the EU-15 and accession countries is taken from the **Eurostat Yearbook** (EC, 2001).

- Company A produces mercury (primary or secondary). Such producers include MAYASA and mercury recovery facilities. As discussed earlier, these may well now include some of the chlor-alkali facilities;
- Company B refines mercury (in some cases) to produce high quality (triple-distilled) mercury which is packaged in capsule (or sachet) form. There are major facilities in Germany and the Netherlands;
- Company C packages capsules with alloys for distribution. This is generally undertaken by national companies using supplies originating from within the EU - although there may be some imports as well; and
- Company D distributes mercury amalgam to dentists together with a wide range of other dental supplies. Within the EU, this market appears to be dominated by two non-EU companies

In relation to emissions of mercury to the environment, it can be seen that the focus of attention will be on Companies A and B since no emissions would (normally) be associated with Companies C and D.

Usage

The use of mercury amalgam for dental fillings generates waste. The waste includes excess amalgam, old fillings which have been drilled out and amalgam present in teeth being extracted.

Although the new separators will recover 95% or more of the waste amalgam, it is sometimes claimed that the prior use of traps and filters provided a reasonably high recovery rate. A study in Denmark found that the mercury in waste water reduced from 57g to 8g per dentist per year with separators fitted (as reported in Arenholt-Bindslev, 1998). These figures can be used to indicate the recovery rate from traps and filters as illustrated in Box 3.1.

Box 3.1: Recovery with & without Separators

Suppose waste quantity was X g/dentist/year and the recovery rates without separators (but with traps and filters) and with separators were A and B respectively. Then, using the waste water figures of 57 and 8 g/dentist/year gives:

for the 'without separators' situation: $X - AX = X(1 - A) = 57$; and
for the 'with separators' situation: $X - BX = X(1 - B) = 8$

Then, $(1-A)/(1-B) = 57/8 = 7.1$ which gives: $1 - A = 7.1 - 7.1B$; which gives $7.1B - 6.1 = A$

Now, if the separators gave a recovery rate of, say, 95%, then $B = 0.95$, giving: $A = 0.64$
and if the separators gave a recovery rate of, say, 98%, then $B = 0.98$, giving: $A = 0.86$

In other words, the Danish work suggests that recovery rates using filters and traps would be of the order of 64-86%.

Taking account of the calculation presented in Box 3.1 and given the widespread implementation of separators within the EU, we estimate an overall recovery rate of around 90%. Once collected, most amalgam is sent to metal recycling plants for mercury recovery - although extracted teeth (which may contain amalgam fillings) tend to be disposed of as clinical waste.

Crematoria

In 1999, 3.5 million people died in the EU and a further 0.5 million died in the three accession countries. Over 30% of the dead (1.2 million = 4 million x 0.3) were cremated. The cremation rates vary greatly from near 0% in Greece and Poland to over 70% in Denmark and the Czech Republic[12]. If it was assumed that there were 8 fillings with 350 mg of Hg per person cremated, this would give a maximum emission (in the EU and three accession countries) of: 1.2 million x 8 x 350 x 10^{-9} = 3.4 tonnes of mercury vapour.

Emissions to Environmental Media

For this and the other products under consideration, the estimation of mercury releases has been based on the two-stage approach used in Sweden (KEMI, 1997):

- the estimation of the distribution factors for the different pathways; and
- the estimation of emission factors for the subsequent releases to air and water.

Distribution factors

For new fillings, the assumed distribution is 60% to new fillings, 20% excess amalgam (which is recovered), 20% amalgam to waste (90% of which is recovered and 10% to sewer). For a current usage of 90 t/year (in the EU and the three accession countries), this would lead to 54 t/year being inserted in new fillings.

For existing fillings (which have a typical life span of around 10 years), the assumed distribution is: 65% to waste (i.e. old filings being drilled out); 10% in extracted teeth (or lost) which are then sent to (clinical) waste (with 25% incineration); and 25% in corpses (with a 30% cremation rate). As indicated in Table 3.7, the usage ten years ago was about 130 t/year (in the EU and the three accession countries), of which 78 t/year (i.e. 60% of 130 t/year) would have been expected to have gone into fillings at that time. Ten years on, these fillings will have come to the end of their life which would give rise to a current 'waste' stream (from these now 'old' fillings) of 78 t/year - i.e. 144% of the current filling rate (= 78/54).

In other words, when considering the quantity of mercury entering the environment, it is necessary to consider losses associated with the insertion of new fillings and the disposal of old fillings. The resultant 'lifecycle' of mercury used in dental amalgam is shown in Figure 3.1. The associated emission factors are discussed further below.

[12] The Cremation Society of Great Britain: *International Cremation Statistics*, available from www.members.aol.com/CremSoc4/Stats.

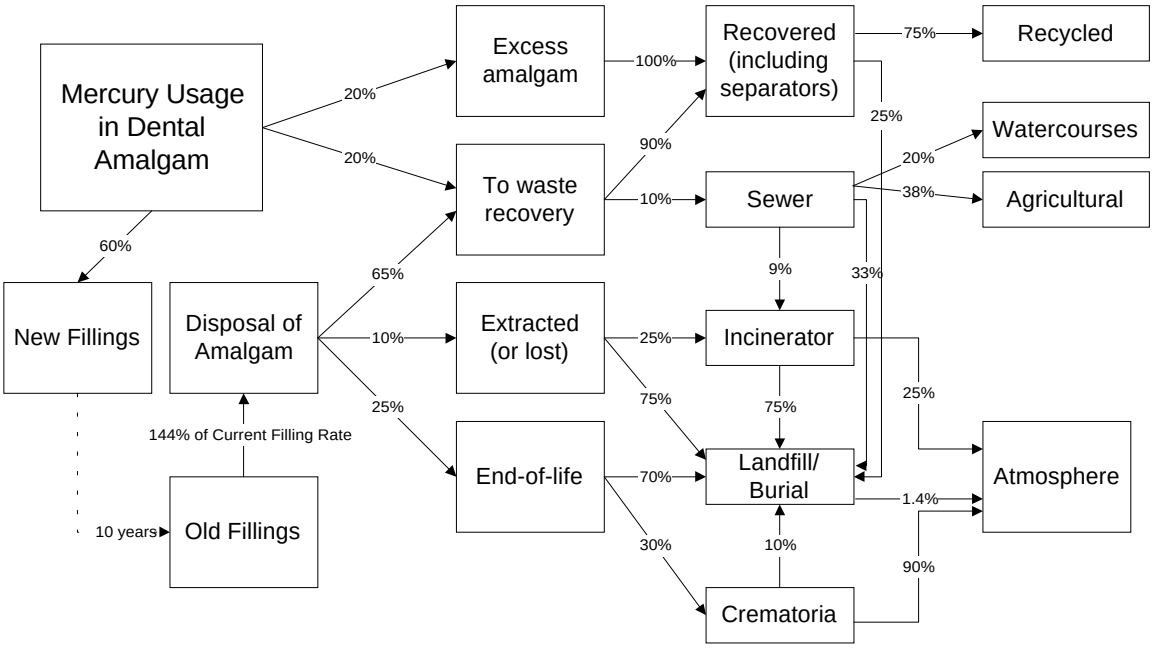


Figure 3.1: Mercury in Dental Amalgam - Lifecycle & Emissions

Emission factors

We have assumed that (relatively, at least) there is negligible emission of mercury to any environmental compartment from recovered mercury. By way of example, the measured emissions at the Finnish plant (which produces mercury from zinc smelting) are less than 0.02% (Finnish Environment Institute, 1999). A current IPPC application for a UK mercury recycling company suggests that compliance with the recent IPPC Guidance Note on 'Best Available Techniques in the Non-ferrous Metals Industries' (EC, 2001) will lead to even lower emissions. Furthermore, mercury losses during the lifetime of a filling (i.e. when in the mouth) have been neglected.

It should be noted that not all 'recovered' mercury will be recycled to re-enter the mercury supply chain. In some cases, recovered amalgam may be disposed of directly to landfill (as clinical waste) whilst elsewhere mercury may be recovered and then disposed of to landfill as mercuric sulphide (as happens with some plants in Finland where lamps are recycled - see S3.4.4). For the purposes of this analysis, we have assumed that 75% of mercury in recovered amalgam is recycled.

As indicated above, 10% of waste amalgam will enter the sewer. WS Atkins (1998) utilise the following factors with regard to the fate of mercury ending up in sewage treatment plants:

- watercourses: 20%;
- agricultural soil: 38%;
- landfill: 33%; and
- incineration: 9%.

These figures were based on practices and trends in the EU in the early 1990s and take into account the treatment of sewage and the disposal of use of sludge for agricultural purposes and have been assumed to remain valid.

In the case of batteries (discussed in S3.3.3), the Swedish report (KEMI, 1997) asserts that 0.5% of mercury disposed of to landfill finds its way to the atmosphere through volatilisation in the first year and, perhaps, 0.1% per year thereafter. Given the relative immobility of mercury in batteries, it will be assumed that these figures can also be applied to mercury in amalgam (and in sulphide form). An annualised figure of 1.4% (based on losses over 10 years) is used - as illustrated in Box 3.2. It is acknowledged that landfill leachate may contain mercury (and other heavy metals) and, for older 'uncontained' sites, may enter local ground/surface waters. However, the concentrations (associated with municipal waste sites, at least) tend not to be significant (Schmid *et al.*, 2000).

Box 3.2: Annualised Losses to Atmosphere from Landfill

In the case of batteries and dental amalgam disposed of to landfill, it has been assumed that there is a loss of 0.5% in the first year and 0.1% per year for the next nine years. This is equivalent to an annual loss of 1.4% per year as the emissions will be comprise those from this and previous years' disposal as shown in the table below.

Year of disposal	Year of Emissions												
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
<1989	0.6%	0.5%	0.4%	0.3%	0.2%	0.1%							
1989	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%						
1990	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%					
1991	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%				
1992	0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%			
1993		0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%		
1994			0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	
1995				0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
1996					0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
1997						0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
1998							0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
1999								0.5%	0.1%	0.1%	0.1%	0.1%	0.1%
2000									0.5%	0.1%	0.1%	0.1%	0.1%
2001										0.5%	0.1%	0.1%	0.1%
2002											0.5%	0.1%	0.1%
2003												0.5%	0.1%
2004													0.5%
Total Emission:		**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**	**1.4%**

With regard to incineration, WS Atkins (1998) indicate that a retention rate of mercury of 50% is reasonable for incinerators across Europe (although possible rates of 90% are also mentioned[13]). The Swedish report however, indicates an overall retention rate of 30%. The consultants believe that advances in incineration technology since the time of those two reports as well as the tightening of emission

[13] Indeed, in its submission to UNEP, Sweden notes that its single hazardous waste incinerator has now virtually eliminated mercury emissions with a 99.9% retention rate.

limits may allow for a 25% value of emissions to the atmosphere to be considered reasonable for the present situation across Europe[14]. Subsequently, the remaining 75% of mercury is likely to be disposed of as hazardous waste to landfill as part of the fly ash residue. In contrast, most crematoria have minimal controls to retain mercury discharges and a value of 90% discharge to atmosphere will be assumed, although about 40% of Sweden's 68 crematoria have now been provided with filters to reduce mercury emissions by 95% or more (Swedish submission to UNEP, 2001).

Summary

Based on an annual consumption of 90 t/year within the EU and the three accession countries and the associated lifecycle and emissions outlined above, the overall end-points were calculated to give the results presented in Table 3.8.

Table 3.8: Dental Amalgam Emissions & End-Points (t/year)

Parameter	**Amount (t/year)**	**Comment**
Consumption	90	Based on S3.2.3 above
End-points:		
Recycled	59.8	It has been assumed that 75% of recovered amalgam is recycled
Water Course	1.4	After sewage treatment
Agricultural soil	2.6	Associated with sewage sludge disposal
Atmosphere	6.5	Dominated by crematoria
Landfill/burial	43.5	
Accumulation[1]	-23.8	This represents the additional flow entering the waste stream from 'old' fillings. As such, this equates to a reduction in the overall 'inventory' of mercury present in dental amalgam (within the EU and the three accession countries) as less mercury is used for new fillings than was the case ten years ago
Check Totals:	*90.00*	

Note:
1) Accumulation relates to the quantity of mercury in circulation within the product rather than to the total quantity of mercury present in the environment associated with the product.

[14] Under **Directive 2000/76/EC on the incineration of waste**, mercury stack concentrations would be limited to 0.05 mg/m^3. This would equate to a maximum mercury emission to atmosphere of the order of 25 kg/year for a 60,000 t/year municipal waste incinerator with a flow through the stack of 60,000 m^3/hr.

3.3 Batteries

3.3.1 Types of Battery

There are numerous types of batteries which may be grouped as follows:

- *'flooded' lead-acid batteries* of which the most common form is the standard battery used to start engines in vehicles, and have been in use since the nineteenth century;
- *'sealed' lead-acid batteries* which appeared in the 1970s and may be used in vehicles but also are widely used in back-up power supplies for computers, etc.;
- *primary (disposable) portable batteries* of which the vast majority are the standard disposable batteries used in the home (torches, toys, etc.); and
- *secondary (rechargeable) portable batteries* of which most are used in electronic equipment (calculators, cameras, mobile phones, etc.).

An indication of the relative scale of usage was derived from the *Europroms* data as shown in Table 3.9.

Table 3.9: EU Imports and Exports of Batteries (1999)

Type of battery	Numbers of batteries in 1999 which were	
	Imported[1]	Exported[2]
Lead-acid batteries (flooded)	34 million	27 million
Sealed lead-acid batteries	43 million	17 million
Primary (disposable) portable batteries	4474 million	5270 million
Secondary (rechargeable) portable batteries	619 million	393 million

Source: Europroms data

Notes

1) The numbers of batteries imported are based on summing the data for intra-EU imports and extra-EU imports for each of the EU countries. As indicated in Section 1.3, these data provide an indication of relative usage (based on trade statistics) rather than a direct measure of consumption.

2) The export figures were derived in the same way as those for imports.

Since lead-acid batteries are much heavier than portable batteries (a typical car battery weighs 13 kg whilst the typical 'C' portable battery weighs 67g), the overall weights of material involved are much closer than Table 3.9 might suggest.

3.3.2 Mercury in Batteries

As discussed in Section 3.1.3, lead ores may contain small amounts of mercury. However, the mercury will be driven off during the smelting process. As such, mercury is not a significant impurity in the lead used in lead-acid batteries (particularly as most of the lead will be re-used and will therefore be re-refined). Furthermore, mercury is not a significant impurity of sulphuric acid (the electrolyte used in lead-acid batteries). In short, lead acid batteries are 'mercury-free' (ICON,

2001 and EC, 2001a). As a result, lead-acid batteries will not be affected by the requirement of the 'end-of-life vehicles directive' for the presence of mercury (not intentionally introduced) to be limited to 0.1% by weight[15] (since the mercury concentrations in lead-acid batteries will be much lower than 0.1%).

In relation to portable batteries, all lithium batteries and secondary (rechargeable) batteries have always been mercury-free. However, there are a number of portable batteries (both 'cylinders' and 'button cells') which contain (or have contained) small amounts of mercury which have been added to enhance performance as indicated in Table 3.10

Table 3.10: Types of Portable Dry Batteries which Contain Mercury

Type & Form	Main Materials	Mercury Present?	Comment
Primary (disposable): Cylinder	Alkaline-manganese (Zn anode, MnO_2 cathode)	Previously, <0.025% by wt. Now mercury free[1]	Standard portable battery which makes up about half of the total numbers of primary portable batteries. Note that zinc-carbon batteries (the other main kind of cylinder battery) are mercury free
Primary (disposable): Button	Zinc-mercury (Zn anode, mercuric oxide (HgO) cathode)	32% by wt.	Formerly used where size is of importance (hearing aids, photography, etc.). Zinc-mercury cells were banned in EU from 1 January 2000
	Silver oxide, Alkaline-manganese, Zinc-air (various designs with Zn anode)	up to 2% by wt	Silver oxide used in watches. Zinc-air particularly used for hearing aids

Notes:

1) Generally, to be 'mercury free' requires the mercury content to be less than 0.0005% (5 ppm) by weight - but see Nordic Ecolabelling requirements below.

3.3.3 Control Issues

Council Directive 91/157/EEC[16] required Member States to prohibit, from 1 January 1993, the marketing of:

- alkaline manganese batteries for prolonged use in extreme conditions containing more than 0.05% mercury by weight; and
- all other alkaline manganese batteries containing more than 0.025% mercury by weight.

Alkaline manganese button cells (and batteries comprising button cells) with higher mercury concentrations were, however, permitted to remain on the market. The

15 Commission Decision 2002/525/EC of 27 June 2002 amending Annex II of Directive 2000/53/EC on end-of-life vehicles.

16 Council Directive 91/157/EEC of 18 March 1991 **on Batteries and Accumulators Containing Certain Dangerous Substances**, OJ L078, 26/03/1991.

Directive also required Member States to provide appropriate systems for the collection, recycling and disposal of spent batteries (and accumulators). These requirements (including mercury content limits) were also used in the Aarhus Protocol (UNECE, 1998).

As of January 1994, the main EU suppliers had agreed to provide 'mercury free' general purpose (i.e. primary cylinder) batteries[17] - although non-members of the European Portable Battery Association continued to import batteries with up to 0.025% mercury by weight (as permitted by Directive 91/157). Commission Directive 98/101/EC[18] required Member States to prohibit, from 1 January 2000, the marketing of:

- batteries and accumulators containing more than 0.0005% (5 ppm) mercury by weight; and
- button cells (and batteries made up of button cells) containing more than 2% mercury by weight.

In Scandinavian countries, ecolabels for primary batteries require a strict limit of 1 ppm of mercury (Nordic Ecolabelling, 2000) - although industry claims that this is below 'natural levels' in other battery materials. For rechargeable batteries, the limit is 5 ppm (Nordic Ecolabelling, 2000a).

3.3.4 Quantities Used

EU Wide

As discussed in more detail below, it is estimated that in the mid-1990s, the quantity of mercury in battery usage in the EU was probably of the order of 40 t/year with over 30 t/year associated with zinc-mercury button cells and over 5 t/year associated with other button cells.

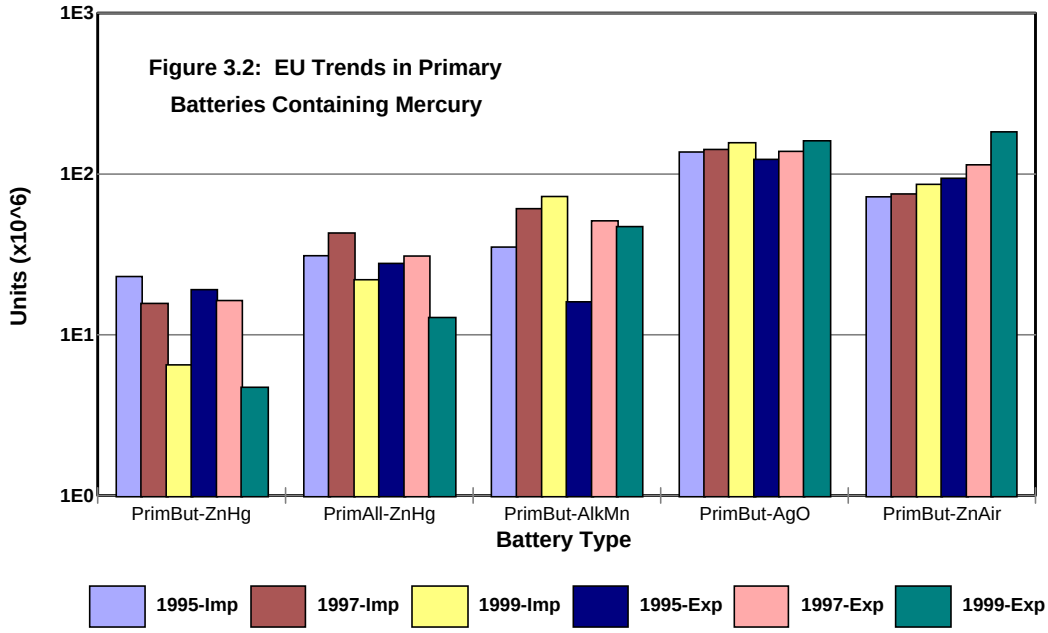
Given the actions of industry to move to mercury free batteries and the implementation of Directive 98/101/EC, the current mercury usage in batteries has probably dropped to the order of 8 t/year. Although zinc-mercury batteries are now effectively banned within the EU and global production has generally ceased, it is worth noting that such batteries are still available through specialist suppliers and, indeed, are still manufactured in the US.

Recent trends in battery usage were explored using *Europroms* as illustrated in Figure 3.2 (overleaf). Particular focus is given to figures for zinc-mercury batteries (predominantly button cells) and other button cells which may contain up to 2% mercury. As can be seen, the numbers (both imports and exports) for zinc-mercury buttons ('PrimBut-ZnHg') have declined sharply since 1997, although this decline is

[17] EPBA (2000): **Effective Recycling of Batteries: The EPBA Two Step Plan**, available from EPBA website.

[18] Commission Directive 98/101/EC of 22 December 1998 **adapting to technical progress Council Directive 91/157/EEC on Batteries and Accumulators Containing Certain Dangerous Substances**, OJ L001, 05/01/1999.

not so dramatic when considering all primary zinc-mercury batteries together ('PrimAll-ZnHg'). In relation to the other kinds of button cell, the figures for silver oxide buttons have remained fairly constant whilst those for other buttons have shown increases in the last few years.



As indicated above, most of the mercury in batteries is associated with button cells and an estimate of button cells sales and associated mercury content has been provided by the industry as shown in Table 3.11. It should be noted that lithium cells (which do not contain mercury) account for about 70% of the primary button sales.

Table 3.11: Mercury Content in Button Cells Currently Sold in EU (& Switzerland) by Members of the European Portable Battery Association

Button Cell	Sales (million)	% Mercury	Quantity of Mercury
Alkaline Button	12.3	0.45	205 kg
Zinc-mercury Button	0	n/a	0 kg
Silver oxide Button	295	0.34	295 kg
Zinc-air Button	243	1.24	1628 kg
Total	**550**	**0.81**	**2128 kg**

Source: consultation - note that figures exclude goods imported with button cells fitted.

There is some divergence between the figures presented in Table 3.11 and the *Europroms* data (as shown in Figure 3.2). In particular, the *Europroms* data suggest a significant trade in zinc-mercury batteries (which are no longer sold by EPBA members) although these 1999 pre-date the ban introduced on 1 January 2000. In addition, the *Europroms* data suggest a higher market share for alkaline button cells than that suggested by the EPBA data.

As can be seen from Table 3.11, the EPBA figures suggest a mercury usage of over 2,000 kg/year in button cells. For comparison purposes, data from ERM (2001) suggest an EU consumption of about 125,000 t/year of primary portable mercury-free batteries which, with a 'natural' level of, say, 3 ppm mercury, would correspond to a mercury flow of about 375 kg/year.

By Country

Germany, France and the UK are the prime consumers of (portable) batteries each accounting for nearly 20% of EU battery sales followed by Italy and Spain (each around 11%). Some further information on battery usage is presented in Table 3.12.

Table 3.12: Mercury Usage in Portable Batteries (mainly Button Cells) by Country (t/year)

Country	c1990	late 1990s	%EU button market[1]	Source & Comment
Austria			2.0%	
Belgium (& Luxembourg)			3.7%	
Denmark	0.4 - 0.9 (1992-93)		1.8%	HELCOM (2001)
Finland		0.75 (1996/97)	1.2%	Consultation - primarily zinc-mercury button cells
France			20.1%	
Germany	16.1 (1991)	3.1 (2000) 125m button cells (excl. lithium) (1998)	20.2%	Submission to UNEP (2001) with 32% recycled leaving 2.1t to waste
Greece			1.9%	
Ireland			0.5%	
Italy			11.0%	
Netherlands	2.6 (1990)		3.8%	Slooff *et al.* (1995)
Portugal			1.4%	
Spain			11.5%	
Sweden		0.8 (1997) 0.1 (1998)	2.6%	Submission to UNEP (2001) - ban on zinc-mercury batteries led to dramatic reduction
United Kingdom		27m button cells (1999)	18.3%	BBMA website (*figure relates to 'consumer sales' and includes lithium cells)*
EU Total	***75***	***8***		***RPA estimates***
Poland			n/a	
Czech Republic		0.22 (2000)	n/a	Submission to UNEP (2001)
Slovenia			n/a	

Note:

1) *ERM (2001) estimate total EU button sales (i.e. including lithium) to be over 1,100 t/year (of the order of 500 million cells/year). The % figures presented relate to button cell waste arising based on sales in 2000.*

3.3.5 Lifecycle & Emissions

Manufacture

Inspection of batteries within a typical EU household will reveal batteries from various countries including the UK, Japan, Germany, Indonesia, China and the USA. Major manufacturers include Duracell, Energizer, Rayovac, Philips, Sony, Varta, and Panasonic. Some countries (for example, Austria) have no production facilities and others (for example, Poland) have facilities for the domestic market.

In relation to button cells specifically, there are only three manufacturing plants in the EU - two in the UK and one in Germany each operated by one of the major manufacturers. Button cells are not produced in any of the three accession countries under study.

It is clear from the information outlined above that not only are large numbers of batteries (and button cells) manufactured within the EU (and some batteries in the three accession countries) but there would also appear to be large numbers of imports and exports (of roughly equal proportions as indicated by Figure 3.2).

Detailed data on individual countries (beyond that presented in *Europroms)* and companies have been difficult to obtain. The most comprehensive data found relate to Germany which suggest that the current mercury usage in batteries is around 3 t/year. A more detailed inspection of the German submission to UNEP (and related documents) reveals a dramatic reduction in mercury consumption in batteries over the last decade which is associated with the decline in use of zinc-mercury button cells (which were banned from January 2000). However, these still accounted for 70% of Germany's estimated consumption of 3.1 tonnes of mercury in batteries in 2000. Similarly, all EU-15 countries report some trade in zinc-mercury batteries (as reported by *Europroms* data) - albeit prior to the introduction of the EU ban on such batteries.

Given that Germany accounts for about 20% of the button cell market and assuming that the German figures can be extrapolated to the EU as a whole, these data suggest a significantly higher figure for the EU as a whole - perhaps 15 t/year than that of around 2 t/year suggested by industry. Although the latter figure relates only to sales by EPBA members (and does not therefore include any sales of zinc-mercury batteries - see Table 3.11), there would appear to be a degree of uncertainty as to the quantities of mercury used in portable batteries - with particular reference to that associated with sales of zinc-mercury batteries (many of which are likely to be imported within products).

In the absence of more detailed data, we shall opt, conservatively, for a current (i.e. 2002) mercury usage in batteries of 8 t/year within the EU and a further 1 t/year in the three accession countries (note that the 50 million population of the Czech Republic, Poland and Slovenia is about 13% of that of the EU's 376 million).

Recycling of Portable Batteries

Although the vast majority of lead-acid batteries are recycled (and have been for many years), the recycling of portable batteries is not so well established.

There are established (portable) battery collection/recycling operations in several countries. 1999 data from Austria, Belgium, Germany and the Netherlands suggest existing battery collection rates of 30% to 55% (EBPA, 2001). However, in Germany, the national 'voluntary' agreement initiated in 1988 was not considered to be an unqualified success (Jörgens & Busch, 2000) and, as a result, the Batteries Ordinance (BatV) was implemented in 1998 which requires:

- retailers to take back all batteries;
- retailers to advise customers of the take back scheme; and
- customers to return batteries to retailers (or recycling centres).

There is no national portable battery collection/recycling operation in the UK, although there are a number of local initiatives (SWAP, 2000). It is worth noting that the near exclusive use of silver oxide button cells in watches which are replaced in the UK, generally, by jewellers lends itself to a recycling scheme and a 75% target appears feasible (SWAP, 2000a).

Consultation has indicated that, from 1 January 2002, a new law in Poland requires producers and importers of portable batteries to recycle 50% of the batteries sold.

Emissions to Environmental Media

As before, the estimation of mercury releases has been based on the two-stage approach used in Sweden (KEMI, 1997):

- the estimation of the distribution factors for the different pathways; and
- the estimation of emission factors for the subsequent releases to air and water.

Distribution factors

The fate of mercury in present in batteries (mainly button cells) is presented in Figure 3.3. Given the relatively short life of a portable battery/cell (ERM (2001) in its report for the battery industry use a figure of three years), there is negligible accumulation and given the nature of batteries, the breakage rate is negligible. These assumptions concur with those used by KEMI. The assumed disposal route distributions (and again these concur with those used by KEMI) are: 20% recovery (as an overall average for the EU and accession countries), 20% to incineration and 60% to landfill (this corresponds to 25% of municipal solid waste (MSW) being incinerated).

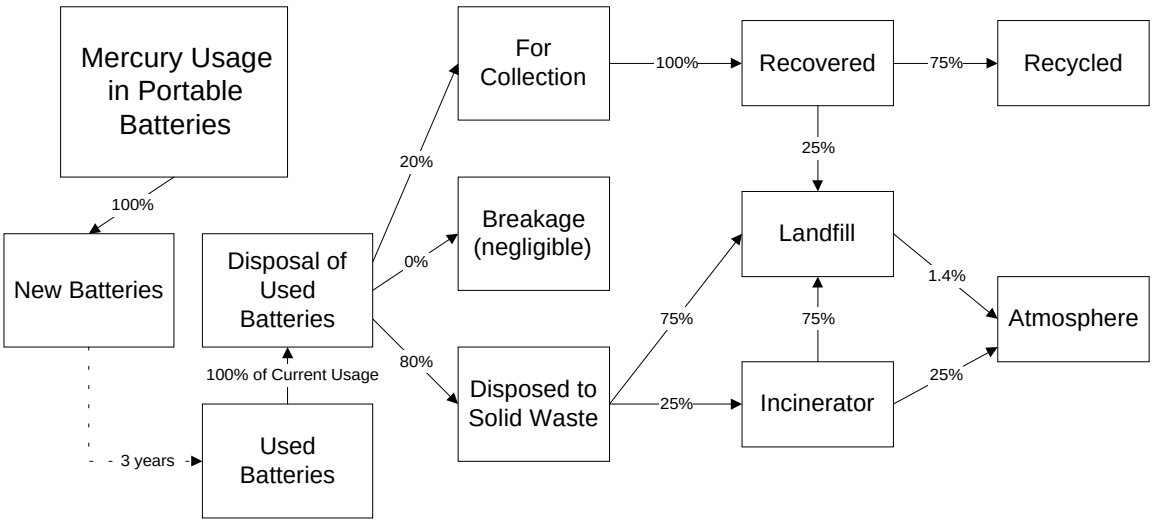


Figure 3.3: Mercury in Batteries - Lifecycle & Emissions

Emission factors

As for the dental amalgam, we have assumed that 75% of the recovered mercury is recycled and 25% sent to landfill. For batteries in landfills, the Swedish report (KEMI, 1997) asserts that 0.5% finds its way to the atmosphere through volatilisation in the first year and, perhaps, 0.1% per year thereafter. As before, an annualised figure of 1.4% is used (to represent average losses over 10 years). With regard to incineration (and as discussed in S3.2.4), an incinerator will emit 25% to atmosphere with the remaining 75% (mainly in fly ash) sent to landfill.

Summary

Based on an annual consumption of 9 t/year within the EU and the three accession countries and the associated lifecycle and emissions outlined above, the overall end-points were calculated to give the results presented in Table 3.13.

Table 3.13: Mercury in Batteries Emissions & End-Points (t/year)		
Parameter	**Amount (t/year)**	**Comment**
Consumption	9.00	Based on S3.3.3 above
End-points:		
Recycled	1.35	It has been assumed that 75% of recovered batteries are recycled
Water Course	0.00	
Agricultural soil	0.00	
Atmosphere	0.55	Dominated by incinerator emissions
Landfill/burial	7.10	
Accumulation	0.00	
Check Totals:	*9.00*	

3.4 Lighting

3.4.1 Types of Lamp containing Mercury

Mercury is present in a range of discharge lamps. Continuing technological development has resulted in not only increased lighting efficiency but also a reduction in mercury content (apart from high-pressure sodium lamps) as illustrated in Table 3.14 by the 'typical' figures provided for the mercury content in lamps in 1993, 1997 and currently.

Table 3.14: Changing Mercury Content in Lamps

Lamp Type	Mercury Present	Uses & Comment
Fluorescent tube (double end)	30-40 mg/tube (1993) 15 mg/tube (1997) 10 mg/tube (currently)	Fluorescent tubes are the most widely used form of artificial light, particularly in commercial and industrial premises. Note that modern tubes use 10% of the mercury used 20 years ago
Compact fluorescent lamp (CFL - single end)	5 mg/lamp (1993, 1997 & currently)	Energy efficient CFLs are widely used for general lighting
High pressure mercury vapour	75 mg/lamp (1993) 39 mg/lamp (1997) 30 mg/lamp (currently)	Used where bright light is required - e.g. security lighting. Small lamps (with less than 1 mg/lamp) are also used for 'executive' car headlamps
Metal halide	60 mg/lamp(1993) 30 mg/lamp (1997) 25 mg/lamp (currently)	Homes and offices
High-pressure sodium	20 mg/lamp (1993) 25 mg/lamp (1997) 30 mg/lamp (currently)	Used for high intensity lighting (note that low-pressure sodium lamps used in street lighting for example are mercury free)
'Neon'	10 mg/tube (estimate)	Low-pressure tubes used in shop signs, etc. Blue colours may contain neon or argon gas and mercury vapour

*Sources: International Association for Energy Efficient Lighting (1993): **Mercury: A Broader Perspective**, IAEEL Newsletter 3/93 (from www.iaeel.org); European Lighting Companies Federation (1997): **Discharge Lamps and the Environment**, Brussels, ELC; and consultation.*

3.4.2 Control Issues

At an International Level

The criteria for eco-labelling of light bulbs were revised in 1999[19] and further revisions are now being processed following a meeting of the European Eco-labelling Board (EUEB) in May 2002[20]. The current specified maximum mercury levels (with those planned in brackets) in lights are as follows:

[19] Commission Decision of 27 July 1999 **Establishing the Ecological Criteria for the Award of the Community Eco-label to Light Bulbs**.

[20] As reported on the European Commission's website: europa.eu.int/comm/environment/ecolabels/news/news.htm.

- single-ended bulbs: 6 mg/bulb (to be reduced to 4 mg/bulb); and
- double-ended bulbs: 7.5 mg/bulb (10,000-20,000 hour life) and 10 mg/bulb (>20,000 hour life). These will be reduced to 5 mg/bulb (>12,500 hour life) and 8 mg/bulb (>20,000 hour life) respectively.

Reduction in mercury content and increased recycling is also encouraged by the Aarhus Protocol (UNECE, 1998) as well as by OSPAR and HELCOM. In the longer term, all fluorescent lamps within the EU are likely to have to comply with mercury limits of 5 mg/lamp (single-ended) and 10 mg/lamp (double-ended) to comply with the proposed RoHS Directive[21]

In view of the continuing drive to reduce the mercury content of lamps, it is worth noting an argument (advanced by industry) that the fossil fuel savings due to use of CFLs over ordinary incandescent mercury-free light bulbs results in net savings of mercury emissions (since mercury is emitted by fossil-fuel combustion for electricity generation).

At a National Level

Several countries have adopted (or are considering) measures to further reduce the mercury usage in lamps as illustrated in Table 3.15.

Table 3.15: Controls for Mercury in Lamps by Country

Country	Control	Source & Comment
Austria	There has been a 'deposit' on fluorescent lamps since 1991 with a 15 mg/lamp limit implemented in 1996 *(Note a similar system for mercury lamps is used in Latvia)*	CTC (1999) & OECD (1995)
Denmark	Being phased out under Order 692 (see Section 1.2)	HELCOM (2001)
Sweden	Further restrictions on mercury in light sources is under consideration (see Section 1.2)	HELCOM (2001)

3.4.3 Quantities Used

EU Wide

The lighting industry is dominated world-wide by three manufacturers which produce over 65% of all lamps - Philips, Osram (Siemens) and GE Lighting.

European Lighting Companies Federation (ELC) figures from 1997 suggest 5.2 t/year of mercury was supplied in lighting units[22] - mainly (over 85%) in fluorescent tubes as illustrated in Table 3.16. More recent figures suggest that although the average mercury content per lamp has declined, this has been more than offset by the increase

[21] Proposed Directive **on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment**, COM(2000) 347, OJ C365E pp 195-197 dated 19 Dec 2000 - which is currently progressing through the European Parliament.

[22] No specific quantitative data have been obtained for 'neon' tubes but the mercury usage is expected to make a negligible contribution to the overall use.

in the number of lamps produced giving a current estimate of 5.9 t/year of mercury in lamps. This figure represents the mercury used in 'European' (rather than EU) lamp production and also includes those lamps destined for export.

The figures quoted above are significantly lower than that of 21 t/year used by WS Atkins (1998).

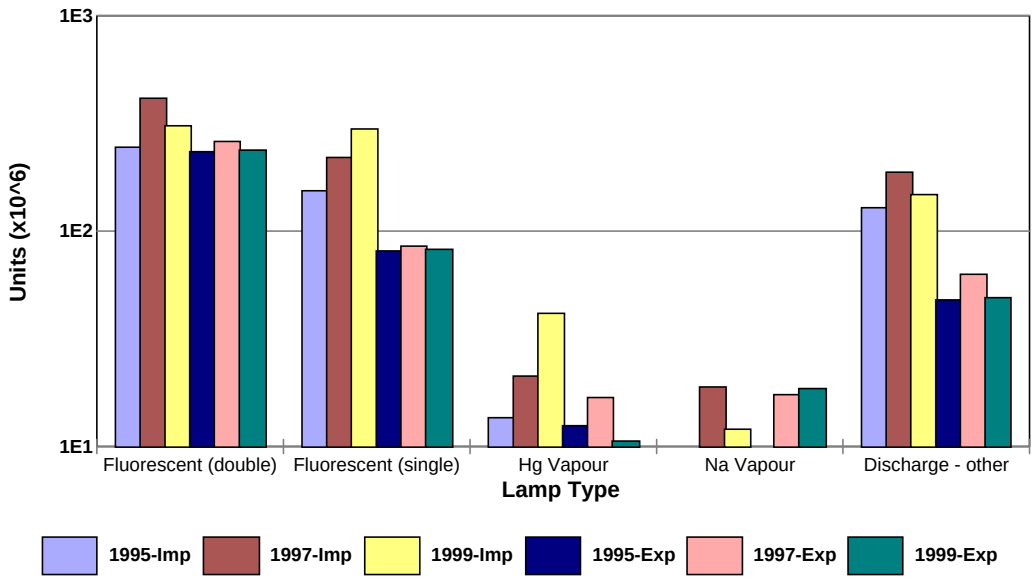
Table 3.16: Mercury Usage in European Lamp Production

Lamp Type	Mercury Used in 1997			Mercury Used Currently		
	mg Hg /lamp	millions produced	Hg used (kg/year)	mg Hg* /lamp	millions* produced	Hg used (kg/year)
Fluorescent tube (double end)	15	300	4,500	10	500	4,000
Compact fluorescent lamp (CFL - single end)	5	40	200	5	140	600
High pressure mercury vapour	30	10	300	30	45	1,300
High-pressure sodium	25	6.4	160	30		
Metal halide	60	2.7	80	25		
Totals:			**5,240**			**5,900**

*Source: European Lighting Companies Federation (1997): **Discharge Lamps and the Environment**, Brussels, ELC; and consultation - note * indicates approximate figures.*

Recent trends in lamp usage were explored using *Europroms* as illustrated in Figure 3.4.

Figure 3.4: EU Trends in Lighting



From Figure 3.4, several observations can be made:

- imports of single-ended fluorescent lamps (CFL) have increased significantly during the late 1990s;
- imports of mercury vapour lamps have increased dramatically during the late 1990s; and
- in broad terms, the numbers of lamps involved are comparable (bar those for 'other' discharge lamps) with those presented in Table 3.16.

Closer examination of the data on mercury vapour lamps indicates that Germany is the lead importer. One potential explanation could be the increased use of mercury vapour headlamps (also referred to as xenon or HID headlamps) for 'executive' cars. However, the mercury content of these new lamps is very low (the order of 0.5 mg/lamp) and work for DG Environment suggests that the overall usage of mercury would be a few kilograms[23] - and this has been confirmed by consultation with a leading supplier.

By Country

Very few meaningful data on lamp use by individual country have been obtained.

3.4.4 Lifecycle & Emissions

Manufacture

Philips has over 40 lamp manufacturing sites in geographic Europe[24] (i.e. including many more countries than those within the EU) although not all produce lamps containing mercury. Osram (Siemens) and GE Lighting have fewer production sites.

There are believed to be manufacturing sites in Belgium, France, Germany, Ireland, Italy, Netherlands, Spain, UK and Poland. In recent years, there has been a move to reduce costs by relocating eastwards and this has resulted in the large companies establishing sites in Poland (Philips), Slovakia (Osram) and Hungary (GE Lighting).

Overall, given the lack of detailed data, the overall figure of 5.9 tonnes of mercury per year in lamps will be used as a basis for subsequent calculations. 12% of this usage (0.7t) has been assigned to the three accession countries (based on relative population and a slightly lower consumption rate) leaving 5.2t used by the EU-15 countries.

Use

Lamps are distributed by wholesalers and retailers and are used directly by the consumer or in the assembly of other products containing lamps.

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23 Sander K *et al.* (2000): **Heavy Metals in Vehicles**, report prepared for DG Environment and dated 27 March 2000.

24 Philips presentation for the 3rd Quarter of 2001 (3Q01) available from www.investor.philips.com.

Disposal

Most European countries have initiated collection and recovery schemes for used lamps. This may result from a desire to encourage recycling and/or from prohibitions on landfilling such items. In the longer term, such schemes are likely to be mandatory under the proposed WEEE Directive[25].

The recovered mercury may be reused as, for example, is done by a UK company which has a contract to recycle 1 million fluorescent tubes per year from UK Government buildings. By contrast, in Finland, there are three plants which recover mercury from fluorescent lights, convert it to mercuric sulphide (the same compound found in the natural ore, cinnabar) and dispose of it to landfill as hazardous waste (HELCOM, 2001).

Emissions to Environmental Media

As before, the estimation of mercury releases has been based on the two-stage approach used in Sweden (KEMI, 1997):

- the estimation of the distribution factors for the different pathways; and
- the estimation of emission factors for the subsequent releases to air and water.

Distribution factors

The mercury in lamps cycle is presented in Figure 3.5.

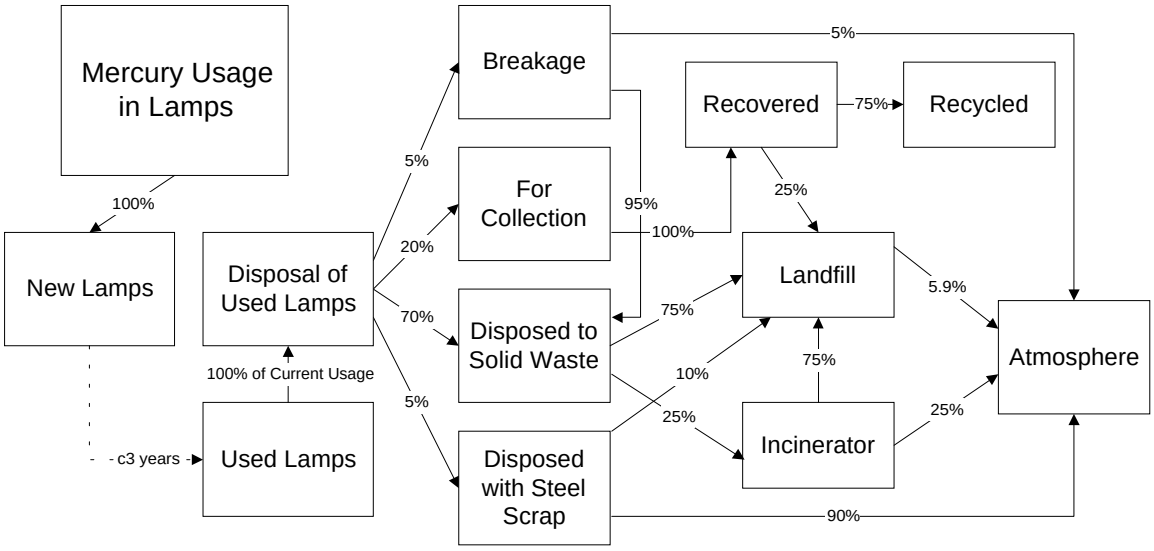

Figure 3.5: Mercury in Lamps - Lifecycle & Emissions

[25] Proposed Directive **on Waste Electrical and Electronic Equipment**, COM(2000) 347 dated 19 Dec 2000 as amended by COM(2001) 315 dated 28 August 2001.

Given the expanding lamp market and typical lamp lifetimes of several years, some accumulation might be expected. However, as indicated in Table 3.16, the average mercury content per lamp has declined giving rise to only a marginal increase in overall mercury usage. On this basis, no accumulation has been assumed. A small proportion of mercury containing lamps may enter the steel scrap recovery cycle (5%) whilst 20% may be recovered directly from collection/recycling schemes. Although a small proportion (5%) may be broken in service, the vast majority, perhaps 70%, will enter the solid waste disposal stream (of which 25% will be incinerated).

Emission factors

We have assumed that there is no emission of mercury to any environmental compartment from recovered mercury. However, as the Finnish operations indicate, a proportion of recovered mercury is then sent to landfill rather than re-entering the secondary mercury production stream (perhaps 25% in total).

For lamps which enter landfills or are broken, most of the mercury vapour will be lost to atmosphere. However, in fluorescent tubes (which account for most of the mercury present in lamps), over 99% of the mercury present is embedded in the tube coating (NEMA, 2000). For lamp breakage, it is assumed, pessimistically, that 5% of the mercury vapour is lost to atmosphere. For landfilled lamps, it has been assumed that 5% is lost in the first year with 0.1% per year thereafter giving an annualised rate of 5.9% (over 10 years) and these values are also used for other landfill operations.

With regard to incineration (and as discussed in S3.2.4), an incinerator will emit 25% to atmosphere with the remaining 75% (fly ash) sent to landfill. In the case of items entering the steel scrap system, the emissions to atmosphere are likely to be relatively higher from arc furnaces and an emission factor of 90% is used (as used by KEMI).

Summary

Based on an annual consumption of 5.9 t/year within the EU and the three accession countries and the associated lifecycle and emissions outlined above, the overall end-points were calculated to give the results presented in Table 3.17.

Table 3.17: Mercury in Lamps Emissions & End-Points (t/year)

Parameter	**Amount (t/year)**	**Comment**
Consumption	5.90	Based on S3.4.3 above
End-points:		
Recycled	0.89	It has been assumed that 75% of mercury recovered from lamps is re-used
Water Course	0.00	
Agricultural soil	0.00	
Atmosphere	0.82	Emissions associated with incineration (34%), scrap steel (32%) and landfill (32%)
Landfill/burial	4.20	
Accumulation	0.00	
Check Totals:	*5.90*	

3.5 Measuring (& Control) Equipment

3.5.1 Overview of Use

Measuring and control equipment that contains mercury includes:

- temperature measurement and control (thermometers and temperature control devices);
- pressure measurement (including sphygmomanometers, barometers, manometers, and vacuum gauges);
- gyroscopes and compasses; and
- other specialist uses (including sling psychrometers (for humidity measurement), steam flow meters, pH-meter and calomel reference electrodes, gas meter pressure-safety devices, air-flow measurement devices, diffusion pumps, carburettor-adjusting devices, sample collectors for offshore oil, Coulter counters for particle measurements, mercury porosimeters (for pore property measurements), etc.).

Approximately 16% of all process instrumentation measures, indicates, or controls temperature. According to a recent survey, industrial temperature measurement is growing at a rate of 3.6% annually including both mercury and non-mercury equipment (Montgomery, 2001).

The following paragraphs provide a brief overview of the technical characteristics of some of the main mercury-containing measuring equipment.

Thermometers

Traditional 'mercury in glass' thermometers used for domestic, medical and scientific purposes have now largely been replaced by alternatives - although mercury is still considered to be the 'best' medium for max-min 'U' thermometers (consultation). Furthermore, the presence of mercury cannot necessarily be excluded from industrial temperature control devices. In closed loop temperature control systems, for example, a device is needed to take the output from the temperature control device and convert it into heating or cooling production. This final control device may well be a mercury displacement relay, especially in industrial environments where heavy duty systems require the final control device to carry high currents, rather than a common electromechanical relay which may wear out quickly (Montgomery, 2001).

Sphygmomanometers

The mercury sphygmomanometer is still seen as the 'gold standard' and is often used as a reference for determining the accuracy of automated devices. However, environmental concerns have led to a change in attitude: in the UK, for instance, it is now generally recommended that consideration is given to the selection of a mercury-free product when opportunity arises (MDA, 2000).

Barometers

A mercury barometer consists of a one metre glass tube filled with mercury. One end of the tube is sealed while the other end of the tube is submerged in a container filled with mercury. The changes in the height of the mercury column (and, hence, atmospheric pressure) are measured in a scale attached to the mercury column. Although other types of barometers exist (such as aneroid barometers), mercury ones are still widely used.

Manometers & Vacuum Gauges

An extension of the mercury barometer is the mercury U-tube manometer. In practical terms, a mercury manometer or gauge is a glass or plastic tube, usually U-shaped containing a certain amount of the metal that moves up and down in response to vacuum (pressure) changes. The vacuum (pressure) is read from marks along the side of the glass or plastic tube. In non-mercury gauges the pressure is read from a dial or a digital display.

An example of vacuum measurement is to be found in milking systems which have vacuum lines that remove and transport milk from cows' udders to a bulk tank. As part of this system, vacuum gauges measure pressure in the vacuum line. By monitoring the gauges, farmers can be alerted to large pressure fluctuations in the vacuum line, which can result in health problems for the cows or indicate operational inefficiencies. Historically, such systems relied on mercury manometers but, generally, these are now only used for calibration (Maine State (US), not dated and consultation).

Sling Psychrometers (Hygrometers)

Sling psychrometers (or hygrometers) are used in the measurement of relative humidity. They consist of two (often mercury) thermometers mounted together, one of which has a cloth wick over its bulb and is called a wet-bulb thermometer. When a reading is to be taken, the wick is first dipped in water and then the instrument is whirled around. During the whirling, the water evaporates from the wick, cooling the wet-bulb thermometer. The temperature difference provides the basis for estimation of the relative humidity.

Coulter Counters

Coulter counters are widely used in hospital laboratories for counting and measuring the size of microscopic particles. Some models contain mercury in the pressure gauge, on-off switch, timing count gauge, vacuum gauge, and possibly other gauges, depending on the model (SHP, 2000).

The useful life of such equipment is usually of the order of 10 years. Data for other equipment from the University of Minnesota show the following lifespans:

- thermometer: 5 years;
- barometer: 10 years;
- manometers: 10 years; and
- sphygmomanometer: 10 years (UMN, not dated).

3.5.2 Control Issues

At an International Level

The position of OSPAR (2000) is that the earlier PARCOM Recommendation 89/3 - which proposed measures on the recycling of mercury contained in measuring (and control) equipment and promoted the replacement of the metal whenever suitable alternatives became available - is being acted upon. As such, OSPAR (2000) recommends that no further controls are necessary but will ask the EC to consider further controls under the Marketing and Use Directive[26].

UNECE (1998) encourages consideration to be given to bans on mercury use in thermometers and other measuring equipment. It is worth noting that, in the longer term, although mercury will not be permitted in electrical and electronic equipment under the proposed RoHS Directive (see S3.4.2), 'laboratory equipment' will be exempted (which is likely to include some of the 'specialist uses' listed above) as indeed are atomic absorption spectrophotometer lamps.

At a National Level

As noted by OSPAR and as shown in Table 3.18, some countries have already taken action regarding the use of mercury-containing measuring equipment - with particular regard to thermometers.

Table 3.18: Controls of Mercury in Measuring (& Control) Equipment by Country

Country	Control	Source & Comment
Denmark	Statutory Order 692 of 1998 bans the use of mercury in products, although derogations for specialist uses in thermometers (to 2004) and other measuring equipment (until further notice) are in place. Danish EPA may also grant exemptions. No mercury thermometers were found in Denmark during a 1996 investigation by the authorities	HELCOM (2001), consultation
France	Mercury thermometers banned under Order of 24 December 1998	consultation
Netherlands	Thermometers being phased out under 1998 Decree (see S1.2) but exemptions for barometers (to 2005), calibration and other specialist equipment	consultation
Sweden	Manufacture and sale of mercury in thermometers and other measuring equipment has been banned since 1993 - but with exemptions (Ordinance 1998: 944)	HELCOM (2001), UNEP (2002)
United Kingdom	Indirect regulation of mercury in medical facilities (i.e. hospitals and doctors' surgeries) through the COSHH Regulations (which govern the safe use and disposal of hazardous substances in the workplace). The cost of compliance is regarded as high which is driving medical staff to seek non-mercury alternatives	MDA (2000), consultation

[26] Council Directive 76/769/EEC **on the Approximation of the Laws, Regulations and Administrative Provisions of the Member States relating to Restrictions on the Marketing and Use of Certain Dangerous Substances and Preparations**.

3.5.3 Quantities Used

Typical Mercury Quantities by Item of Equipment

Table 3.19 summarises the average content of mercury in different types of measuring equipment. It should be borne in mind that, in most cases, there are now non-mercury equivalents which tend to be used in preference.

Table 3.19: Typical Quantities of Mercury Contained in Measuring Equipment	
Type of Equipment	**Quantity of Hg Contained (g)**
Medical thermometers	0.5 - 1.5
Industrial thermometers – special application thermometers	10
Household thermometers	0.5 - 2.25
Gas debit meter	up to 25
Counter collectors	~70
Sphygmomanometers	85
Gyroscopes/compasses	15 - 400
Manometer	up to 150
Barometer	40 - 1000
Porosimeter	1,500
Environmental manometer	3,000
Pressure transmitter	8,000
Sources: ERM, 1998; WS Atkins, 1998; Environment Canada (2000); and consultation.	

Previous EU Wide Estimates

WS Atkins (1998) indicates that 55 t/year are used in measuring equipment[27], based on data available from reports dating back to the mid-1990s.

Another study performed in the late 1990s was the Swedish study on mercury in products as a source of transboundary pollution transport (KEMI, 1997). The Swedish report differs in the respect that measuring and control equipment are considered as one group of products. However, while this group includes thermostats (which in the other two reports - WS Atkins (1998) and ERM (1998) - belong to the electrical control equipment group), they do not include switches which are grouped with lighting equipment. The KEMI report uses the widely-quoted study by Maxson *et al.* (1991) as a starting point and estimates that in 1997 the consumption of mercury in measuring equipment in Europe was 40% lower than the 1989 consumption reported by Maxson *et al*. With a 1989 consumption of just over 115 t/year, the 1997 consumption was believed to be 70 t/year.

Table 3.20 provides an overview of the most recently documented data on the consumption of mercury in measuring equipment.

[27] Although ERM (1998) uses slightly different values, they are based on those derived by WS Atkins.

Table 3.20: Recent Estimates of EU Mercury Consumption in Measuring & Control Equipment		
Product type	**WS Atkins, 1998**	**KEMI, 1997**
Medical thermometers	23 t/year	70 t/year*
Other thermometers	28 t/year	
Other measuring equipment	4 t/year	
Total	**55 t/year**	**70 t/year***
*also includes thermostats and applies to all of Europe (i.e. not only EU Member States).		

Current Estimates at a National Level

An indication of mercury usage in measuring (and control) equipment at a national level is given in Table 3.21.

Table 3.21: Mercury Usage in Measurement (& Control Equipment) by Country (t/year)	
Country	**Commentary**
Austria	Thermometers are believed to be the main source of mercury in the domestic waste stream. However, the mercury emissions are decreasing due to continuous replacement of mercury measuring devices with alternative ones (electronic and gallium ones are mentioned as the preferred options) (UNEP, 2002)
Denmark	The quantity of mercury used in measuring equipment in Denmark in 1993-93 was estimated to be 0.5 t/year (HELCOM, 2001). Consultation with the Danish EPA suggests that current usage is 0.1-0.2 t/year. This figure is believed to be equally divided between sphygmomanometers, laboratory equipment and chemical reagents. The decline in the use of mercury in Denmark was rapid in the early 1990s. From the late 1990s, however, the levels of use of mercury have been largely stabilised. As the use of mercury in thermometers has been phased out, mercury in thermometers may account for only 10% or less of total mercury contained in measuring equipment
Finland	In 1987, the mercury consumption in measuring equipment was estimated as 1.6 t/year (OECD, 1995). By 1996/97, this had reduced to about 300 kg/year (consultation)
France	In 1990/92, the mercury consumption in measuring equipment was estimated as 12.5 t/year (OECD, 1995)
Germany	In 1987/90, the mercury consumption in thermometers was estimated as 11-15 t/year with a further 20 t/year used in laboratories (OECD, 1995)
Netherlands	In 1989, the mercury consumption in measuring equipment was estimated to be less than 2.8 t/year (OECD, 1995)
Sweden	Usage has been reduced to tens of kg per year - see below
United Kingdom	Usage has been reduced to around 1.6 t/year - see below
Poland	It has not been possible to collect data on the use of mercury in measuring equipment in Poland. There is no central institution for registering products introduced to the market and the Polish Ministry of Health does not hold any information on the quantities of mercury used either. At present, there is no regulation requiring those who manufacture or import such articles to report on the quantities manufactured or imported. Therefore it is very difficult if not impossible to quantify the consumption of mercury in measuring equipment in Poland (based on information from team members in Poland)
Czech Republic	Consultation suggests that the quantity of mercury to be found in thermometers and sphygmomanometers in Czech hospitals to be 15-25t. Assuming that the annual consumption of mercury does not exceed 10% of this, the current consumption of mercury in the Czech Republic is assumed to be no more than 1.5-2.5 t/year

Sweden

In 1997, the annual sales of mercury in 'other regulated products' was 40-50 kg. This category includes thermometers (0.2 kg) and other measuring equipment (including porosimeters (9 kg), switches, contacts, relays and thermostats (HELCOM, 2001). The low consumption in these applications was the result of legislation introduced in the early 1990s (see Section 3.5.2).

Since 1997, there has been a gradual decline in the already limited use of mercury in measuring equipment. Consultation with the Swedish authorities has revealed that in 1998 only 250-300 mercury thermometers were still in use in all Swedish hospitals containing approximately 0.5-0.6 kg of mercury. Today, Swedish hospitals (effectively Swedish County Councils) do not purchase mercury thermometers or sphygmomanometers any more. It is believed that almost all mercury thermometers have been removed from Swedish hospitals and local authorities intend to remove the few remaining sphygmomanometers in the near future.

Mercury collection programmes in Sweden have targeted thermometers over the years in the 1990s and about 0.69 tonnes of mercury were collected from 1992 to 1996 across the country.

With regard to the use of mercury in sphygmomanometers, such equipment is used in both industrial and medical facilities, although mercury-based ones are only used in medical facilities over the last ten years. Those used are usually of small size and intended to be placed around toes and fingers. For the time being, the use of mercury in such equipment is exempt from mercury-related legislation, however fibre optic technology is being developed for medical use after showing good results in industrial applications. Consultation suggests that the estimated use of mercury in sphygmomanometers at present is considered to be lower that 1 kg per year.

Overall, it is likely that the current mercury consumption in measuring and control equipment will be of the order of 20-30 kg/year.

United Kingdom

Information on the use of mercury in measuring equipment in the medical sector of the UK is fragmented. There are separate Supplying Authorities for England, Scotland, Wales and Northern Ireland within the UK's National Health Service (NHS). Moreover, individual Health Trusts (hospitals) may bypass the central state authorities and purchase equipment directly from suppliers and manufacturers.

The English branch of NHS Purchase and Supply Services confirmed that mercury use in measuring equipment is declining. Figures for 2001 show a 50% decrease in the number of supplied thermometers (82,320) and sphygmomanometers (1,224) compared to 2000 figures. Naturally, some hospitals may have simply abandoned the central state suppliers and have opted for direct purchase from the manufacturers/merchants. Nevertheless, the downward trend is clear. As already indicated, one of the prime reasons behind this reduction is believed by consultees to be the requirements imposed by workplace safety

legislation and, in particular, the Control of Substances Hazardous to Health (COSHH) Regulations (as mentioned in Table 3.17). All of the thermometers supplied by the English NHS Supplies Agency in 2000 were manufactured in China. On the other hand, around 60% of the supplied sphygmomanometers were of EU origin with the rest originating mainly from Japan.

Information from the Northern Ireland region also indicates a significant reduction in the number of mercury-filled units over the last 3-4 years, again mainly due to the requirements of the COSHH Regulations. The central NHS Supplies Agency in Northern Ireland no longer purchases mercury-filled thermometers nor sphygmomanometers - although such equipment is still in use.

Other users of mercury-containing measuring equipment in the UK include laboratories, veterinary practitioners and educational establishments. In addition, there are a number of specialists who buy, sell, restore and repair antique barometers.

Consultation with companies manufacturing and supplying mercury-containing measuring equipment has shown that:

- in general, consumption of mercury has decreased over recent years and several consultees indicated that this reduction exceeds 50% compared to 1998 figures;
- the decline in the use of mercury in the UK is expected to reflect EU trends; and
- a significant proportion of measuring equipment originates from non-EU countries. The majority of clinical thermometers are imported from China, while Japanese and Indian products are also widely distributed.

Initial estimates of the quantities of mercury used in the UK are given in Table 3.22.

Table 3.22: Estimates of Present Use of Mercury in Measuring Equipment in the UK

Product	Estimated volume of UK sales	Typical Hg content (g)	Estimated consumption of mercury (kg/year)
Medical thermometers	350,000 [1]	0.5 - 1.5	300
Domestic and industrial thermometers	350,000	0.5 - 10	780
Sphygmo-manometers	5,700	85	485
Barometers	875	40	35
Total for above uses:			**1,600 kg**

Source: Consultation with state authorities and private companies.
Note: 1) It has been assumed that the English NHS Supplies figure accounts for 80% of total NHS-supplied thermometers in the UK (England accounts for 50 million of the UK's 60 million population). Additionally, it has been suggested that individual UK Health Trusts (hospitals) may have purchased collectively equal or even greater numbers of thermometers than those provided by the NHS. Furthermore, industry consultation suggests that there is a significant additional UK market for clinical/medical thermometers (presumably directly to consumers).

Summary

The use of measuring equipment that contains mercury has been shown to be on the decline, although insufficient data have been obtained to provide precise detail in most countries - particularly in southern Europe.

In some countries, such as Denmark and Sweden, thermometers and other measuring equipment containing mercury are not imported nor sold any more while the use of mercury thermometers has been banned in France and the Netherlands. In the UK a significant reduction in mercury consumption has taken place since the mid-1990s.

For the accession countries, limited information exists and the consultants have not been notified of any legislation imposed or other trend in the use of mercury in measuring equipment. For the Czech Republic, only an initial estimate of a consumption of 1.5 - 2.5 t/year has been reached.

Overall, a 50% reduction in the consumption figures quoted by WS Atkins in 1998 seems a reasonable scenario. This would bring mercury consumption in measuring equipment in the EU to about 28 t/year. For the three accession countries, a total of 5 t/year (on the basis of Czech data) could also be suggested as reasonable.

3.5.4 Lifecycle and Emissions

Manufacture

As outlined above, many thermometers and other measuring equipment are imported, primarily from China, India and Japan.

Within the EU, there are major manufacturers in the UK and Germany. In general, it is believed that emissions of mercury during the manufacture of measuring equipment are minimal and they do not contribute significantly to the total mercury load of the different environmental compartments. This is considered in more detail in Section 5.

Product Use and Disposal

For the estimation of mercury releases from the use of mercury-containing measuring equipment, two stages were followed based on the emission patterns indicated in the Swedish publication (KEMI, 1997):

- the estimation of the distribution factors for the different pathways; and
- the estimation of emission factors for the subsequent releases to air and water.

The lifecycle and emission factors are shown in Figure 3.6 and discussed in more detail below.

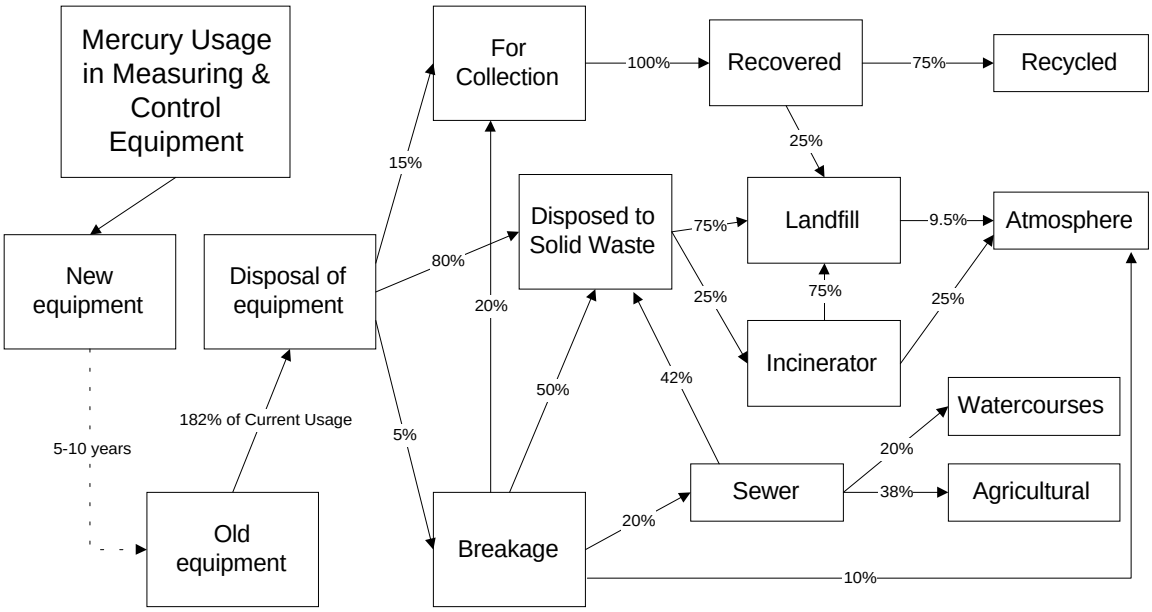

Figure 3.6: Mercury in Measuring & Control Equipment - Lifecycle & Emissions

Distribution factors

For collection, the Swedish report assumed a factor of 10%. Although this figure may have been seen as high if applied to EU countries in general a few years ago, there is little doubt that there has been a substantial increase in the awareness of the problems presented by mercury in recent years. As a result, we have assumed a distribution factor of 15% for the collection of manometers, barometers and sphygmomanometers which are due to be replaced (or possibly serviced) by specialist companies and for the recovery of mercury from industrial measuring equipment (where the bulk of mercury may be difficult to dispose of to the solid waste stream or to the sewer).

With regard to disposal, it is assumed that 80% of mercury used will be disposed of as solid waste (75% of which will go to landfill). Additionally, 5% of equipment is assumed to break before it completes its useful lifetime.

Although the current 'inputs' to mercury in measuring equipment have reduced significantly in recent years, typical lifetimes are of the order of 5-10 years. As a result the quantities of mercury 'outputs' (to the waste and recovery streams) will be significantly greater to reflect the greater consumption of 5-10 years ago. For the purposes of this analysis, the consumption of 5-10 years ago will be assumed to correspond to the earlier figure of 55 t/year derived by WS Atkins (for the mid-1990s) for the EU together with the 5 t/year for the three accession countries (which has been assumed to have remained relatively constant over the last few years). Five to ten years on, these items of equipment will have come to the end of their life which would give rise to a current 'waste' stream (from these now 'old' equipment) of 60 t/year - i.e. 182% of the current usage rate (= 60/33).

Emission factors

As before, it has been assumed that there is no emission of mercury to any environmental compartment from recovered mercury and that 25% of the recovered mercury is sent to landfill.

In the event of breakage, 10% is assumed to be lost to atmosphere, 20% to sewer, 20% is recovered and 50% enters the solid waste stream. The above figures are based on the assumption that the majority of mercury from broken measuring equipment is generally disposed of to landfill (or to sewer to a lesser extent) and it is only collected and recycled by medical and industrial facilities where proper equipment and procedures for recovery are invariably in place.

For landfilled materials, it has been assumed that 5% is lost in the first year with 0.5% per year thereafter giving an annualised rate of 9.5% (over 10 years). It should be noted that in contrast to the products previously considered, much of the mercury entering the landfill (in measuring and control equipment) will be in liquid elemental form.

With regard to incineration (and as discussed in S3.2.4), an incinerator will emit 25% to atmosphere with the remaining 75% (fly ash) sent to landfill.

Summary

Based on an annual consumption of 33 t/year within the EU and the three accession countries and the associated lifecycle and emissions outlined above, the overall end-points were calculated to give the results presented in Table 3.23.

Table 3.23: Mercury in Measuring and Control Equipment Emissions & End-Points (t/year)

Parameter	**Amount (t/year)**	**Comment**
Consumption	33.00	Based on S3.5.3 above
End-points:		
Recycled	7.21	It has been assumed that 75% of mercury recovered from equipment is re-used
Water Course	0.12	
Agriculture	0.23	
Atmosphere	8.08	Atmospheric emissions dominated by emissions from landfill (58%) and incineration (39%)
Landfill/burial	44.43	
Accumulation[1]	-27.06	This represents the additional flow entering the waste stream from 'old' equipment. As such, this equates to a reduction in the overall 'inventory' of mercury present in measuring and control equipment (within the EU and the three accession countries)
Check Totals:	*33.00*	

Note:
1) Accumulation relates to the quantity of mercury in circulation within the product rather than to the total quantity of mercury present in the environment associated with the product.

3.6 Electrical Control and Switching Equipment

3.6.1 Overview of Use

Mercury finds various applications in the field of electrical control and switching equipment primarily due to its excellent conductivity and its liquid state at room temperature. Stability and reliability coupled with low corrosion potential and relatively low price make mercury components for electrical and electronic equipment very useful and appealing. Types of products that may contain mercury include:

- switches, contacts and relays:
  a) level (and motion) switches, which are used when switching on and off is triggered by movement;
  b) reed switches, known as circuit breakers, with their electrical contacts wetted with mercury to provide instant closure and opening of a circuit;
  c) multipoled switches, which are used in machinery with moving parts;
  d) thermo switches, which are used in thermostats;
  e) silent switches;
  f) mechanical switches (for example, solenoids), which are used when frequent switching is necessary; and
  g) contacts which are used to close, break, transfer or guide the current to different streams of current. A number of contacts forms a relay.

- mercury vapour tubes and arc-rectifiers:
  a) valves that produce radiation of electromagnetic nature, such as X-rays, microwaves and radio waves, with the help of tubes containing mercury vapour; and
  b) arc-rectifiers used in industrial control equipment and welding torches (OSPAR, 2000; ERM, 1998).

The following paragraphs provide a brief overview of the technical characteristics of some of the main mercury-containing measuring equipment.

Switches

Switches are used to control (open and close) electrical circuits. They are activated by a change in temperature (temperature switch - i.e. a thermostat), pressure (pressure switch), or position/motion (tilt switch, float switch).

Mercury switches frequently have far fewer components than mechanical type electrical switches with levers, springs, pivoting electrodes, etc. The use of a hermetically sealed container, inside which switching takes place, ensures that there is no exposed spark, thus these devices can be safely operated in explosive atmospheres (fuel areas, hospital rooms, coating booths, etc.) (Kahlsico, 2000).

Silent/tilt switches are small tubes with an electrical contact at one end of the tube. As the tube tilts, mercury collects at the end where the electrodes are situated. Such switches

are used in numerous applications such as: light switches, sump pump float controls, automobile trunk lamps, chest freezer door lamps, and washing machine lift covers (Sass *et al.*, 1994). Although consultation indicates that there is a general move away from mercury switches, they are still used widely in security applications (for example, motion alarms).

Mercury safety valve/mercury flame sensors detect the presence of a pilot light for a gas burner and controls the flow of gas into the burner if the pilot light is out. They find applications in both residential and commercial equipment (e.g. ovens) (Environment Canada, 2000).

Reed switches are small circuit controls with mercury wetted electrical contacts (Environment Canada, 2000). Mercury is able to provide an instantaneous circuit when the switch is closed and to permit instantaneous current interruption when the circuit is broken. Reed switches eliminate the static produced in ordinary hard-contact-type switches. Such equipment is used in applications where static would impair the operation of the electronic device. Reed switches are reported to be less expensive than solid-state alternatives and therefore are still favoured by some users. However, solid-state relays and electro-optical switches are rapidly replacing mercury-wetted switches (Sass *et al.*, 1994 and consultation). Mercury-wetted reed switches are often used for applications where electronic noise and interference from switch 'bounce' are a concern (Inland Ispat Indiana Harbor *et al.*, 2001).

Relays

Relays are devices in which low power signals (from control devices) are used to actuate larger power operations (such as motorised valves) by opening or closing electrical contacts in a circuit. Mercury-wetted 'reed' relays are used for switching of signals and power levels since the load does not affect either contact life or performance as no solid metal-to-metal contact occurs. They are primarily used in test, calibration and measurement equipment where stable contact resistance over the life of the product is necessary. They are usually produced in relatively small quantities as they are intended to be used in specialist equipment (Inland Ispat Indiana Harbor *et al.*, 2001).

Displacement/plunger relays are generally used for high-current, high-voltage applications, resistance heating, welding, lighting, power supply switching, and industrial process controllers (Inland Ispat Indiana Harbor *et al.*, 2001).

Other Applications

The transistor, developed in 1947, has replaced most vacuum tubes and some gas-filled tubes. Some tubes, however, have not been replaced by solid-state devices, although inroads are being made. Examples of such applications include microwave ovens, radar installations, X-ray machines, or mercury-arc rectifiers. Gas-filled mercury tubes use a pool of mercury as the cold cathode pool (Sass *et al.*, 1994).

Mercury arc rectifiers were extensively used in the past to provide DC in high power applications, powers ranging from kilowatts up to a few megawatts, at voltages ranging

from 110V to 30kV. An arc between a pool of mercury and a metal anode which only allows current to pass in one direction are the basic components of the rectifier. Multiple anodes are typically used, fed from a multiple-phase transformer, with the arc jumping from the cathode pool to each anode in sequence. There may be three, six or even twelve transformer phases, each feeding one anode. Six and twelve-phase systems used star-connected three-phase transformers with interphase transformers between the star common connections. Construction is either a glass bulb, cooled by an external fan or water jacket, or a steel tank for very large units with capacities above about 500 amperes. However, mercury arc rectifiers have now been made totally obsolete by semiconductors, although there are a few still in service in old installations (Harrison, 2001 and consultation).

3.6.2 Control Issues

At an International Level

PARCOM Recommendation 89/3 proposed, among others, measures on recycling mercury used in electrical equipment; it also promoted the use of equipment not containing mercury, where the cost of replacement is not extremely high (OSPAR, 2000). HELCOM Recommendation 18/5 was concerned with the reduction of emissions and subsequent pollution of mercury resulting from electrical (and light) equipment (CTC, 1999). Reduction in mercury usage and increased recycling is also encouraged by the Aarhus Protocol (UNECE, 1998).

Although there is a general presumption against future mercury usage in switches and relays under the proposed RoHS Directive, many current uses will be exempted including not only laboratory/medical equipment but also thermostats and heating regulators.

Consultation with the association representing the European manufacturers of (electrical) domestic equipment (CECED) has shown that a relatively recent CENELEC[28] safety standard (EN 60335-1:1994/A13:1998) which gives presumption of conformity of domestic appliances (refrigerators, washing machines, toasters, etc.) to the EEC Low Voltage Directive (LVD) 73/23/EEC contains the following provision:

> "*Appliances shall not incorporate components containing liquid mercury*" (sub-clause 22.41).

Additionally, a new IEC[29] standard (IEC 60355-1:2001), which is being currently transposed to Europe, indicates that:

> "*Appliances shall not incorporate components, other than lamps, containing liquid mercury*" (sub-clause 22.41).

[28] European Committee for Electrotechnical Standardisation.

[29] International Electrotechnical Commission.

The CECED secretariat has notified the consultants that their member associations have confirmed that their member companies duly conform with the above standards and therefore, mercury is no longer used in domestic electrical appliances. It should be noted that associations from Finland, Greece, Ireland, Luxembourg and Portugal do not appear in the list of members of CECED (although national associations of manufacturers from Norway, Switzerland and Turkey are included) (CECED, 2002).

At a National Level

Specific controls over limiting mercury use in electrical equipment have been implemented in various countries as indicated in Table 3.24.

Table 3.24: Controls for Mercury in Electrical Equipment by Country

Country	Control	Source & Comment
Denmark	Being phased out under Order 692 (see Section 1.2) although some switches, relays and electrodes exempt until further notice	HELCOM (2001) and submission to UNEP (2001)
Netherlands	Under the 1998 Decree (see Section 1.2), most mercury containing electrical equipment now banned	consultation
Sweden	Manufacture and sale of mercury in electrical equipment has been banned since 1993 (with some exemptions). Manufacture and sale of all such equipment now banned by The Chemical Product Ordinance 1998:944	HELCOM (2001) and submission UNEP (2001)

3.6.3 Quantities Used

Typical Quantities of Mercury Contained in Electrical Control Equipment

The typical quantities of mercury contained in electrical and switching equipment are given in Table 3.25. As for measuring equipment, there are now non-mercury equivalents in most cases, which tend to be used in preference.

Table 3.25: Typical Quantities of Mercury Contained in Electrical Control Equipment

Type of equipment	Quantity of Hg contained (g)
Modern mercury switch	0.01 - 1
Flame sensor (for gas installations)	2.5
Silent switches* (for lights)	2.6
Displacement switch and solenoids*	up to 130
Thermostat (old mercury tilt switch*)	3 - 6
Freezer light*	2
Washing machine* (power shut off)	up to 2
Automobile light switch*	0.7 - 1.5 (average 0.8)
Automobile ABS switch	~3
Automobile ride-control switch	1
Mercury vapour tubes and arc-rectifiers*	up to 5000 (average 250)

Sources: Inland Ispat Indiana Harbor et al., 2001; Ecology Center et al., 2001; US EPA, 2000a; and consultation.

*Note: * indicates items that are now believed to be obsolete.*

Previous EU Wide Estimates

The ERM (1998) and WS Atkins (1998) reports provide slightly differing figures of mercury consumption in electrical control equipment. ERM indicates a consumption of 24 t/year, while WS Atkins assumes a 29 t/year consumption. The KEMI report (1997) has incorporated electrical control equipment into electrical and lighting equipment and has considered thermostats as part of the measuring equipment group, hence a comparison of the Swedish estimates with those made by the former two reports is unrealistic. Additionally the estimated Swedish report figure of >230 t/year of mercury consumption in electrical lighting and control equipment in 1997 is applicable to all Europe (i.e. both EU and non-EU countries).

Current Markets

The European markets for electrical control and switching equipment are large. Those for switches and relays are each of the order of a billion euros per year (EPIA, 2002 & VDC, 2000). Of course, these markets cover the full range of equipment (ranging from simple mechanical switches to solid-state relays) and it is unlikely that the mercury containing equipment[30] market accounts for more than 1% (consultation).

Despite numerous approaches to companies and trade associations, very little definitive information has been provided. Although there remains a considerable degree of uncertainty, it would appear that:

- the current EU mercury switch market is of the order of five to ten million switches per year - split between those with up to one gramme of mercury per switch and smaller switches with the order of 0.1 gramme of mercury per switch;
- the current mercury consumption is perhaps several tonnes of mercury per year;
- the mercury switch market has declined by about 25% in recent years as customers have moved to non-mercury alternatives;
- although there are manufacturing facilities in Belgium and Germany (and possibly elsewhere), there are many imports, primarily from the US; and
- mercury vapour tubes and arc rectifiers are no longer supplied.

Against this background, the current consumption of mercury-containing equipment will be taken, perhaps conservatively, as 8 t/year for the EU with a further 1 t/year in the three accession countries (i.e. 12% of EU figure). Although these figures are uncertain, these findings would suggest that the figures advanced in the earlier reports (as outlined above) were unduly conservative.

Current Estimates at a National Level

An indication of mercury usage in electrical control and switching equipment at a national level is given below.

[30] Note that a simple modern mercury switch sells for about one euro.

Denmark

The 1992-93 consumption of mercury in electrical control and switching equipment in Denmark was estimated to be 0.2-0.4 t/year with a decreasing trend given that in 1990 the respective figures were 0.3-1.6 t/year.

According to the Danish EPA, electrical switches and relays have been banned since 1 July 1994. The use of mercury is only allowed in small film-wetted switches. A realistic estimate of the present situation in Denmark indicates that the use of mercury in electrical components is only marginal.

Sweden

Swedish legislation which came into force in 1993 prohibits the manufacture, import and sale of mercury containing electrical components. Therefore, the consumption of mercury in Sweden is believed to be negligible. However, consultation with the Swedish authorities yielded information on the quantities of mercury which are still present in Sweden as illustrated in Table 3.26.

Table 3.26: Mercury Stored in Electrical Components in Sweden (2002 estimates)

Type of equipment	**Estimated Hg quantity (tonnes)**
Electrical and technical products stored in industry [1]	27 - 32
Electronics built into products (dealt with by dismantlers)	2 - 3
General household uses (heating oil-level indicators, doorbells, other unusual applications) [2]	1 - 2
Rectifiers for power sea cables	1.8
Mercury components in cars	1
White goods switches	0.3

Source: Consultation
Notes: 1) also includes thermometers and other measuring devices
2) also includes indoor/outdoor thermometers and barometers

It is worth noting that European carmakers have reportedly phased-out mercury light switches in automobiles since 1992 in order to meet the Swedish ban on vehicles containing mercury (Ecology Center *et al.*, 2001 and consultation). Furthermore, the EU ELV Directive bans the use of mercury in vehicles from 1 July 2003[31].

United Kingdom

Consultation suggests that the UK market for mercury switches is of the order of a million switches per year, which represents a significant portion of the EU market. The leading UK supplier imports the 'basic' switches from the US which are then incorporated into further casings and/or mountings for resale.

[31] Although, the presence of small amounts of mercury in HID (xenon) headlamps (as discussed in S3.4.3) now being fitted to some Swedish cars will be exempt.

3.6.4 Lifecycle and Emissions

Similarly to measuring equipment, the basis for emissions estimates for mercury contained in switching and electrical control equipment is the KEMI (1997) report and the WS Atkins 1998 report (the latter for product manufacture only).

Product Manufacture

In general, it is believed that emissions of mercury during the manufacture of switching and electrical control equipment are limited. This is discussed further in Section 5.

Product Use and Disposal

For the estimation of mercury releases from the use of mercury-containing switching and electrical control equipment, two stages were followed:

- the estimation of the distribution factors for the different pathways; and
- the estimation of emission factors for the subsequent releases to air and water.

Distribution Factors

The lifetime of mercury switches and other mercury containing electrical control equipment could extend to decades. In practice, the lifetime will be determined by that of the item within which the equipment is contained - which is more likely to be of the order of 5 - 10 years. For the purposes of this assessment, it will be assumed that the quantity of mercury requiring disposal will be 150% of the current usage - i.e. 13.5 t/year which is equivalent to current usage (9 t/year) plus 50% additional inputs from 'old' equipment.

The 1997 Swedish report assumed an arbitrary 10% distribution factor for re-collection of mercury-containing switches and electrical equipment. Switches and other mercury-containing electrical equipment are rarely collected for recycling when they are replaced by owners but are more likely to end up in the recycling stream if replaced by professionals. Additionally, some switches and thermostats and especially vapour tubes and arc-rectifiers are bulky items that cannot simply be disposed of to the solid waste stream as they are. As for measuring equipment, a factor of 15% will be used here to accommodate more recent practices in the recycling of hazardous substances like mercury from electrical equipment.

An additional 5% factor is used to account for the quantities of mercury in switches and other equipment which are being recovered by the steel scrap industry and used in steel production.

Physical breakage is a very infrequent occurrence with respect to mercury switching and electrical control equipment. Such articles may fail to perform but they seldom break and release their mercury contents. Hence, 'breakage' emissions will be negligible.

The remaining 80% of the mercury has been assumed to enter the solid waste stream.

The lifecycle (and emission factors) are shown in Figure 3.7.

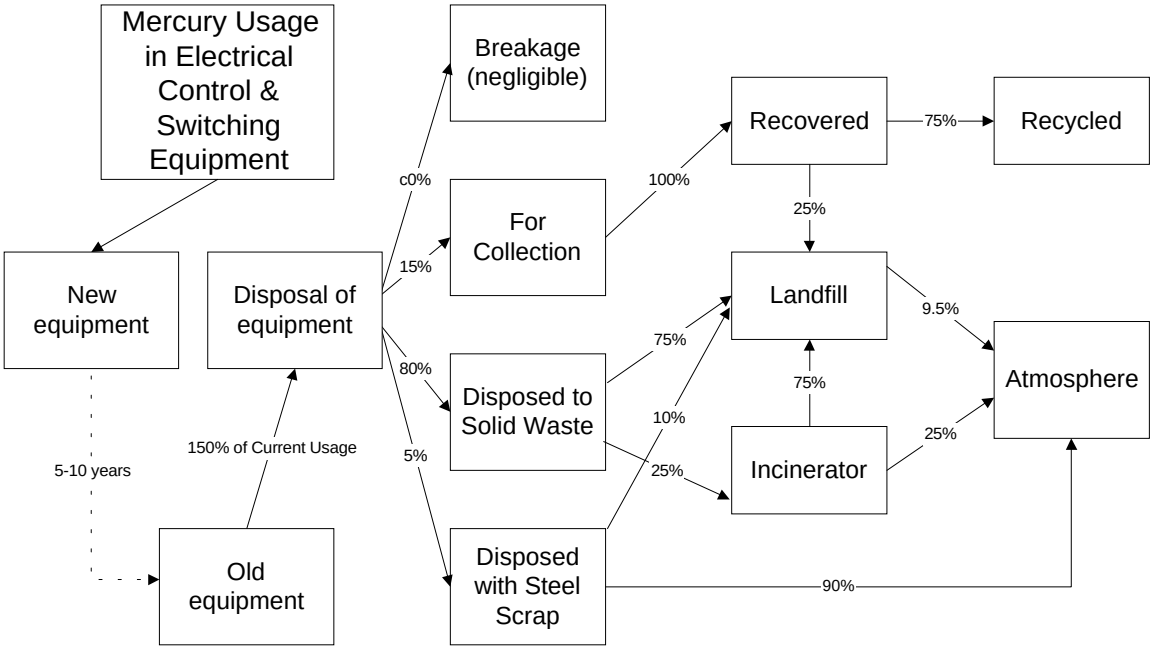

Figure 3.7: Mercury in Electrical Control and Switching Equipment - Lifecycle & Emissions

Emission factors

As before, it has been assumed that there is no emission of mercury to any environmental compartment from recovered mercury and that 25% of the recovered mercury is sent to landfill.

For landfilled materials, it has been assumed - as for measuring and control equipment considered previously - that 5% is lost to atmosphere in the first year with 0.5% per year thereafter giving an annualised rate of 9.5% (over 10 years).

With regard to incineration (and as discussed in S3.2.4), an incinerator will emit 25% to atmosphere with the remaining 75% (fly ash) sent to landfill.

In the case of items entering the steel scrap system, the emissions to atmosphere are likely to be relatively higher from arc furnaces and an emission factor of 90% is used (as for lamps - see S3.4.4).

Summary

Based on an annual consumption of 9 t/year within the EU and the three accession countries and the associated lifecycle and emissions outlined above, the overall end-points were calculated to give the results presented in Table 3.27.

Table 3.27: Mercury in Electrical Control and Switching Equipment Emissions & End-Points (t/year)

Parameter	Amount (t/year)	Comment
Consumption	9.00	Based on S3.6.3 above
End-points:		
Recycled	1.52	It has been assumed that 75% of mercury recovered from equipment is re-used
Water Course	0.00	
Agriculture	0.00	
Atmosphere	2.30	Atmospheric emissions associated with emissions from landfill (44%), incineration (29%), and scrap steel processing (26%)
Landfill/burial	9.68	
Accumulation[1]	-4.50	This represents the additional flow entering the waste stream from 'old' equipment. As such, this equates to a reduction in the overall 'inventory' of mercury present in electrical control and switching equipment (within the EU and the three accession countries)
Check Totals:	*9.00*	

Note:
1) Accumulation relates to the quantity of mercury in circulation within the product rather than to the total quantity of mercury present in the environment associated with the product.

3.7 Other Products

3.7.1 Overview

It is claimed that mercury is (or has been) used in a variety of other products including 'executive toys', pads to absorb rifle recoil, arm/leg weight bands, golf balls, etc. Other uses include cosmetic and pharmaceutical products - although, as indicated in S3.1.6, the latter are beyond the scope of this study.

During the course of this study, the most comprehensive listing of mercury containing products found was one prepared for the Minnesota Pollution Control Agency which is reproduced as Annex 3. Although most of the products listed are covered in the preceding sub-sections, the following paragraphs outline some of the other uses of mercury which cannot be readily classified under the main usage categories which have been examined in this report. Only limited information is available on these uses and little or no information on the consumption of mercury has been obtained.

3.7.2 Golf Balls

There is often anecdotal evidence that mercury is used in golf balls. However, research indicates that although mercury filled centres were experimented with in the early 1900s, there have been no golf balls with mercury centres on the market for many years[32] - and this has been confirmed by consultation with a number of well known golf ball manufacturers.

3.7.3 Pigments

Natural (and synthetic) cinnabar (mercuric sulphide) has been used as the red pigment, *vermilion*, for thousands of years (in China, at least). In Europe, the use of vermilion was a vital part of paintings by Monet, Rembrandt and Titian. Given the concerns over health and the environment associated with the use of mercury and its compounds in recent decades, its commercial use has practically disappeared.

However, although becoming increasingly hard to find, artists in Europe can still buy vermilion pigment (some of which is still natural cinnabar imported from China).

Historically, mercury pigments have been used in plastics (as indicated in Annex 3). Although it would appear that the French company specifically identified still sells cadmium pigments, there is no indication that mercury pigments are sold.

[32] See, for example, www.erupegolf.com

3.7.4 Childrens' Shoes

Many references[33] may be found to the use of mercury in shoes which have flashing lights - mainly designed for children. However, few of these references provide the requisite detail to permit informed comment. It would appear that although some of the earliest versions of these shoes (dating from the early 1990s) did incorporate a liquid mercury tilt switch, these were soon replaced with a non-mercury pressure switch. The lights tend to be powered by lithium (non-mercury) button cells.

3.7.5 Lighthouses

Lighthouses around the world rely on rotating a large lens assembly, weighing up to a few tonnes, every 10 seconds or so. Traditionally, the lens assembly floats in a bath of a few hundred kilograms of mercury. Although there is anecdotal evidence that the presence of the mercury may have contributed to depression and, even, suicide amongst lighthouse personnel, most lighthouses are no longer manned.

Although some such arrangements have been replaced with non-mercury alternatives, others retain their mercury baths. No estimate of the number of lighthouses still using mercury baths in the EU has been derived although the Swedish authorities estimate that there is 1t in use in Swedish lighthouses (consultation).

3.7.6 Gold Mining

Mercury may be used to extract gold from crushed ore through the formation of an amalgam. The amalgam is then decomposed by the addition of nitric acid or, more simply, by heating. Although this is a significant use of mercury which accounts for 5-10% of the global mercury supply (as suggested by Vonkemann, 2000), gold mining within the EU is minimal.

In South America, there is widespread artisanal gold mining in which mercury is used and released to the environment. Of note is that one of the countries involved is French Guiana (or Guyane) which is an overseas department of France. Current gold production is estimated to be about 3 t/year (of up to 200 t/year for South America as a whole) and it is estimated that for each tonne of gold produced, one tonne of mercury is released to the environment (representing up to 50% of the mercury used in the process) (Veiga, 1997). On this basis, mining in French Guiana could result in the emission of around 3 t/year of mercury to the environment.

3.7.7 The Use of Mercury in Medicines

Although technically outside the scope of this study, this section has been included to indicate the relative usage of mercury in medicines. Studies undertaken by the US Food and Drug Administration (FDA) have shown that several ophthalmic, otic, injectable and topical drugs and vaccines for humans may contain mercury compounds such as

[33] See, for example, http://sneakers.pai.com/lightup.htm.

thiomersal (thimerosal in the US), phenylmercuric acetate, and phenylmercuric nitrate. Furthermore, a large variety of mercury compounds was identified in human and animal homeopathic products and in traditional medicine products (such as herbal pills from China). It was estimated that about 1,000 homeopathic products in the US market may contain small amounts of mercury. The mercury compound content of the above products varied from 1 ppm to more than 100 ppm and the total quantity of those compounds used in all products was estimated to be approximately 75-80 kg/year (FDA, 2001).

In Ireland, the Health and Safety Authority identified a plant which uses mercury as a preservative in eye care products. Recent mercury consumption has been about 5 kg/year with emissions of less than 0.5 g/year to waste water (emission factor: <0.01%) and zero emissions to other environmental media (Irish submission to UNEP, 2001).

Thiomersal

Mercury is used in medicinal products, mainly in the form of thiomersal. The substance finds applications particularly in vaccines either as a preservative to avoid microbial contamination due to repeated withdrawal of doses from a container or for other reasons. In Sweden, it has been calculated that by taking the yearly consumption of these vaccines and a mercury concentration of 25 µg per dose, the total amount used is around 20 grams per year (Swedish submission to UNEP, 2001).

A thorough toxicological assessment of the use and potential risk of thiomersal, when administered to humans, has been made by the European Agency for the Evaluation of Medicinal Products (EMEA). The assessment concluded that there was no risk of acute toxic reactions in the doses used. However, a risk of sensitisation was identified and all products containing thiomersal should carry a warning statement in the catalogue text. Furthermore, the EMEA recommends the use of thiomersal-free vaccines for young children (EMEA, 2000).

3.7.8 Mercury in Cosmetic Products

Mercury and its compounds are not permitted in cosmetics marketed within the EU[34], although trace amounts are permitted in preservatives (as discussed above) for eye make-up and eye make-up remover[35].

A study undertaken by the Danish National Environmental Research Institute (NERI) in 1999 found that several brands of soap and cream with significant levels of mercury are sold in Tanzania. These products are used to make skin and hair lighter in colour and their origin was found to be the EU. Soaps usually contain 1-3% mercury iodide, while the creams contain 1-10% mercuric ammonium.

[34] Council Directive 76/768/EEC of 27 July 1976 relating to cosmetic products.

[35] Eighth Commission Directive 86/1999/EEC of 26 March 1986 adapting Council Directive 76/768/EEC to technical progress permits up to 0.007% (70ppm) of mercury as thiomersal or phenylmercuric salts in eye products.

The distribution of mercury-containing cosmetics products is prohibited in the EU, North America and many African countries. In Tanzania, the import of soap containing mercury is forbidden although large volumes of such products are smuggled into the country and are used for the bleaching of skin and hair. During this study, three brands of soap and two brands of cream were found in Tanzanian markets. All three soaps were marketed as antiseptics and had a declared concentration of 2% mercury iodide (or 0.88% mercury). On the other hand, the two creams claimed to produce a lighter skin colour and contained hydroquinone, allantoine and vitamins. Analyses revealed that the three soaps contained on average 0.69% mercury (i.e. slightly less than labelled), while the suspicions about the presence of mercury in the two creams were not confirmed. Four of the samples belong to products made in the UK while the fifth was of Italian origin (NERI, 1999).

The Danish report indicates that such products can also be found in areas of the EU. By way of example, the Danish EPA issued a press release on 22 March 2000 according to which seven brands of mercury-containing soap had been found in shops in Copenhagen. At the time it was believed that the products were made in the UK and Spain and were sold to the Danish companies either directly or through dealers in France (Danish EPA, 2000a). The soaps were intended to be used as bleaching agents and contained 1-3% mercury iodide. Later that year (in December 2000), the Danish authorities issued a new press release according to which five shops in Copenhagen had been notified to the police for marketing soaps containing mercury. New brands of such soaps were identified (apart from those known since Spring 2000) and their origin was Italy and Spain (Danish EPA, 2000b).

An Irish company is reported to produce mercuric iodine soap. The company uses 95 t/year of potassium mercuric iodine solution which is equivalent to 17.2 t/year of mercury. No effluent discharges of air emissions were detected during on-site investigations by the Irish authorities while solid waste is forwarded for disposal off the company's site (Irish submission to UNEP, 2001).

In summary, although the sale of mercury soap is prohibited in the EU (as it is a cosmetic product), its manufacture for export outside the EU is not. However, it would appear that some of these products are sold within the EU (perhaps after being exported to and then re-imported from a non-EU country).

3.7.9 Mercury in Chemical Agents

Another significant 'other' use of mercury is the use of mercury containing chemicals. In the laboratory, the standard COD 'dichromate' test involves the use of mercuric sulphate to suppress chloride interference (if chloride levels are high). It is worth adding that, in light of concerns over mercury, one of the leading suppliers now offers an alternative manganese III method. In the chemical industry, mercury compounds are used as catalysts for the production of, for example, vinyl chloride and urethane foams. In the fireworks and explosives industry, mercuric fulminate is sometimes used as a detonator.

The Swedish government is considering an amendment of Ordinance 1998:944, by which the use of mercury in chemicals for analysis and reagents would be banned from 1 January 2004, since earlier information campaigns for phasing out reagents such as those used in the determination of COD in laboratories have been unsuccessful (Swedish submission to UNEP, 2001).

Mercury in Hospital Laboratory Reagents

Two tissue fixatives used in medical laboratories contain significant amounts of mercury: Zanker's solution and B5. While the former contains 72 g of mercury per litre, the latter contains 37 g of mercury per litre. These reagents can be substituted in many cases by other fixatives but not in all. Different fixatives have different fixative and staining properties and require the preparation of different specimens, therefore practitioners may still show some preference to mercury-containing fixatives for reasons of convenience (Torke, 1994).

3.7.10 Other Mercury-containing Hospital Equipment

Significant amounts of mercury may be found in Bougie tubes and Canter tubes used by medical practitioners in hospitals. The Bougie tube is a mercury weighted instrument that is used to 'pound' an opening in the oesophagus when there are cancerous growths or other obstructions. The Canter tube is a tube almost 2 meters long which is filled with mercury and is inserted down the patient's gastrointestinal tract. Information from the US indicates that non-mercury alternatives are now available for both these devices (Torke, 1994).

3.7.11 The Use of Mercury as an Archery Stabiliser

Stabilisers aim to provide a smooth feeling of the bow, to reduce the possibility of torque affecting arrow flight and to reduce vibration during and after shots. Mercury-filled rods were introduced as anti-torque stabilisers in the late 1960s along with other liquids - although the use of mercury was never popular in Europe (consultation).

Later, liquids were replaced by foam and sand. Many modern bows use lightweight, stiff aluminium or carbon rods with rubber mountings which are fitted between the rod and the end-weights in order to dampen vibration. The most up-to-date stabilising system consists of multiple thin rods with a moveable weight which allows the archer to tune the stabiliser (Elliot, 2000).

3.7.12 Rifle Recoil

Recoil suppression systems in rifles and shotguns usually incorporate a lead or steel weight mounted on springs to reduce recoil. There are, however, alternative systems which use liquid mercury (170g or more per gun) which are widely marketed in the US.

3.7.13 Mercury-containing Lamps in LCD Monitors

Liquid Crystal Displays contain mercury due to the presence of back lamps that contain the metal. The typical number of back lamps in a portable (laptop) computer is 2 but a 38 cm (15 inch) LCD monitor will normally contain 4 lamps and an even larger monitor could contain 6, 8 or more lamps in order for the appropriate levels of brightness to be maintained. The mercury content of an LCD back light was reported in 2001 to be between 2.5 and 3.5 mg. It is worth noting that the updated EC eco-label criteria for personal computers which were issued on 22 August 2001 require that the background lighting of LCD monitors should not contain more than 3 mg of mercury per lamp on average (Commission Decision 2001/686/EC) (AEA Technology, 2001).

Screens using organic light emitting diodes could replace mercury-containing LCD monitors, however their use is considered more feasible in mobile phones at the moment rather than computers. It is expected that this technology will be introduced to portable computers by the year 2004.

Within the EU, laptop sales are of the order of 7 million per year and account for about 20% of personal computer sales. This would give a mercury consumption of:

7 million laptops x 4 lamps/laptop x 3 mg/lamp = 84 kg/year

With regard to televisions (for which the introduction of an EC eco-label is currently under way), LCD technology is also applicable - although CRT displays are to be found in the great majority of equipment. From an environmental point of view, LCD technology is superior in that it allows for the mercury back lights to be easily separated from the display and be recycled (AEA Technology, 2002).

It should be noted that the contribution of such lights is probably included in the overall 'lamp' figures presented in Section 3.4.

3.7.14 Summary

From the preceding discussion, it is clear that mercury has been or may continue to be used in a diverse range of products. Although determining the quantities involved is very uncertain, Table 3.28 provides some preliminary estimates.

Table 3.28: Mercury Usage in Other Products

Type of product	Estimated Mercury Usage in the EU
Golf balls	Negligible
Pigments	Perhaps up to 50 kg/year
Children's shoes	Negligible (as most shoes containing mercury will have been disposed of)
Lighthouses	Number of lighthouses with mercury baths not known but quantity of mercury in use could be of the order of 10-15 tonnes. The associated mercury consumption will be low, perhaps up to 100 kg/year

Table 3.28: Mercury Usage in Other Products	
Type of product	**Estimated Mercury Usage in the EU**
Gold mining	Mercury usage (in French Guiana) likely to be 6 t/year or more with 3 t/year emitted to the environment
Medicines	Based on US data of 75 - 80 kg/year, the EU consumption is not expected to exceed 100 kg/year as a worst case scenario
Cosmetic products	From the Irish data of 17.2 t/year and given that several UK, Italian and Spanish companies are active in the business (given the large African market), a consumption of 50 t/year is possible, although some UK companies deny that they manufacture soap in the UK. However, the use of such products (and associated emissions) will tend to be outside the EU.
Chemical agents and hospital laboratory reagents	Perhaps of the order of 100-200 kg/year (note that agents are gradually being replaced with non-mercury alternatives)
Archery stabiliser	Negligible
Rifle recoil	Probably, small to negligible use in the EU
LCD monitors	80-100 kg/year in laptops but may well have already been accounted for in 'lamps'
All the above	**The order of 50 t/year within the EU with, perhaps, a further 5 t/year in the three accession countries**

3.8 Summary of Product Usage and Emissions

The overall consumption of mercury in the products under study is of the order of 200 t/year within the EU and the three accession countries being considered (Czech Republic, Poland and Slovenia).

Although much of the mercury is recovered for re-use from the disposal of mercury containing products, most of the mercury will end up in landfills. Since mercury usage is generally declining, the quantities of mercury entering the waste stream are now greater than those entering into product use. This, in turn, is leading to a reduction in the total 'inventory' of mercury within the products in circulation. However, since mercury cannot be simply destroyed, there will continue to be a mercury build up in the environment - most noticeably in landfills.

The results of the analyses presented in the previous sub-sections are summarised in Table 3.29

Table 3.29: Mercury Usage in Products within EU and Three Accession Countries[1]

Product	Current Usage (t/year)	End-points and Quantities (t/year)					Change in Inv Q[2] (t/year)
		Re-use	Air	Water	Soil	Landfill	
Dental Amalgam	90.0	59.8	6.5	1.4	2.6	43.5	-23.8
Batteries	9.0	1.35	0.55	0	0	7.1	0
Lighting	5.9	0.9	0.8	0	0	4.2	0
Measuring Equipment	33.0	7.2	8.1	0.1	0.2	44.4	-27.1
Electrical Equipment	9.0	1.5	2.3	0	0	9.7	-4.5
All the above	**146.9**	**70.7**	**18.3**	**1.5**	**2.8**	**108.9**	**-55.3**
Other Products[3]	c55	not determined					

Notes:

1) Czech Republic, Poland and Slovenia.

2) Inv Q represents 'inventory quantity' - i.e. the quantity of mercury in circulation within products.

3) Likely to dominated by cosmetic products (see S3.7.8 and Table 3.28).

4. OVERVIEW OF EXPOSURE TO MERCURY

4.1 Background to Discussion

This section provides a general discussion of the sources of environmental and human exposure to mercury. It is intended to provide an overview of the total exposure to mercury, from all sources. Section 5 then provides an estimate of the environmental exposure and exposure of humans via the environment for the uses of concern for this study. The remainder of this section is structured as follows:

- consideration is given first to environmental releases, both anthropogenic and natural with quantitative data presented on releases, based on a review of recent literature;
- fate and behaviour of mercury in the environment is then discussed, with information presented on speciation in the environment and transport within and between environmental media;
- a summary of relevant data on environmental concentrations is provided together with an indication of changes over time. This provides a basis on which to put the estimated exposure for the uses of concern into context; and
- finally, an overview of human exposure - both occupation and non-occupational - is given.

4.2 Releases of Mercury to the Environment

4.2.1 Introduction

The natural releases and anthropogenic emissions of mercury have been investigated over the years and estimates on the relevant figures have been reached. However, these estimates are under constant revision as more monitoring data become available, as knowledge of the complex lifecycle of mercury improves and as additional up-to-date information is collected. As will be shown in the next paragraphs, while anthropogenic emissions of mercury have reduced in real terms due to increased awareness, controls and regulation as well as advances in technology, the contribution of anthropogenic sources to the global mercury load seems to have increased recently. The underlying reason is that there has been a dramatic fall in the estimates of the contribution of natural sources. This does not mean that the actual natural releases have been reduced, but instead, reflects the realisation by scientists that earlier estimates had probably been unduly conservative.

4.2.2 Natural Releases of Mercury into the Environment

There is a variety of natural sources of mercury released into the environment, including forest fires, volcanoes, evaporation from soil or water and volcanoes, amongst others. As detailed by UNEP (2002), historical deposition of mercury from anthropogenic sources contributes significantly to global mercury cycling, making estimation of natural sources problematic. As indicated above, estimates of natural

emissions (as opposed to the emissions themselves) reported in the literature have declined in recent years. For example:

- Jones and Slotten (1996) report global estimates from the 1980s for atmospheric emissions of 60 t/year from volcanic activity, 1-2,000 t/year from other continental sources (crustal degassing, forest fires and biological mobilisation), 2,000 t/year from the world's oceans and 200 t/year as fluvial input;
- Lindquist *et al.* (1991) estimate total global natural emissions to be of the order of 3,000 t/year;
- more recent emissions estimates are provided by Mason *et al.* (1994) who reported global natural emissions of 1,050 t/year; and
- Within the EU, the most recent estimate for natural emissions is of the order of 200 t/year (EC, 2001b).

Most 'natural' emissions are in elemental form - although those from volcanoes tend to be mercuric oxide. In broad terms the emissions from the oceans are roughly equal to the atmospheric deposition over the oceans (based on Lee *et al.*, 2000)

4.2.3 Anthropogenic Releases of Mercury into the Environment

There are a number of sources of anthropogenic mercury emissions into the environment. Until relatively recently, it was considered that the anthropogenic emissions were of a similar order to 'natural' emissions. However, it has recently been suggested that anthropogenic emissions account for 60-80% of the total mercury emissions (EC, 2001b and UNEP, 2002). Within Europe (both EU and non-EU countries), it has been estimated that the total anthropogenic emissions have reduced from 860 t/year in 1980 to about 340 t/year by 1995 due, largely, to a combination of improved emission control measures and changes in industrial processes (EC, 2001b). At a global level, recent estimates of anthropogenic releases are of the order of several thousand tonnes (UNEP, 2002).

Apart from those associated with the production and use of mercury-containing products which are the focus of this study (as discussed in Section 3), other anthropogenic sources of mercury emissions include:

- combustion of fossil fuels - mercury is a natural component of both coal and oil at concentrations typically of the order of 0.1 to 1 ppm and 0.01 to 1 ppm respectively. The EU consumes about 600 and 300 million t/year of oil and coal respectively (mainly in power stations[36]). Taking (geometric) mean mercury concentrations of 0.3 ppm for coal and 0.1 ppm for oil would lead to potential emissions of the order of 150 t/year.

[36] It must be emphasised that the mercury emissions from oil-fired power stations are much lower than those from coal-fired power stations. This is because the fuel oil used in power stations has a very low mercury content. In other words, the mercury emissions will be associated with the processing of the crude oil in the refineries and combustion of other products rather than with the combustion of the fuel oil. The behaviour of mercury in oil processing is complex as described in NRM (2001).

- chlor-alkali plants - only four countries out of those of interest (Denmark, Luxembourg, Ireland and Slovenia) do not have chlor-alkali plants using mercury cells - with Germany having by far the greatest number. The total quantity of mercury involved is of the order of 10-15,000t (Vonkeman, 2000 and ERM, 2000). Within the EU, the 1999 mercury consumption in chlor-alkali plants was of the order of 150 t/year (based on OSPAR, 2001 and Vonkeman, 2000). The associated emissions (mainly to atmosphere) have been steadily reducing over the past 20 years to less than 10 t/year in 2000 (Eurochlor, 2001). However, significant quantities of mercury, perhaps 40 t/year, are unaccounted for[37] (OSPAR, 2001);
- other industrial processes - with particular reference to pig iron and steel production and cement production which together generated estimated (EC, 2001b) emission of around 35 t in 1995 across Europe (i.e. both EU and non-EU countries); and
- (old) submarine ballast tanks - mercury used to be used in submarine ballast tanks and was a major source of near-shore marine contamination. There are a number of lost submarines which are rumoured to still contain significant amounts of mercury.

Mercury also enters the environment through the disposal of solid and liquid wastes, some of which will be associated with the production and use of mercury-containing products (as indicated in Section 3).

4.3 Fate and Behaviour in the Environment

4.3.1 Speciation and Transformation of Mercury in the Environment

Overview

Mercury is a liquid under standard conditions but it occurs in a variety of different forms in the environment, with transformation processes between forms depending upon the conditions in the environmental medium in question. These forms include elemental mercury, mercuric (Hg^{2+}) compounds and organomercurials (particularly methyl and dimethyl mercury). The main source of organic mercury compounds is a microbial conversion of inorganic mercury entering surface water. In the air, dimethyl mercury, which is volatile, readily dissociates (by photolysis) to form methyl mercury. Methyl mercury is stable and bio-accumulates - particularly in aquatic organisms - and is the most toxic form of mercury.

Mercury in the Atmosphere

In the atmosphere, the main form present - and the majority of that emitted - is elemental mercury. Elemental mercury has a half-life in the atmosphere of several

[37] Similar situations are found elsewhere. For example, detailed figures for 1996 determined a mercury consumption in US chlor-alkali plants of 150 tonnes, emissions of 8 tonnes and 101 tonnes unaccounted for (Sznopek & Goonan, 2000).

months to a year. Due to its relatively long lifetime in the atmosphere, elemental mercury in the vapour phase can be transported over large distances.

Whilst monovalent mercury is not found in the atmosphere, bivalent mercury may be present in organic form (methyl or dimethyl mercury) or inorganic form (for example, mercuric chloride). Bivalent forms may be attached to particulate matter (especially in the sub-micron range) and may result from (slow) oxidation of elemental gaseous mercury. The bivalent forms have a much shorter half-life in the atmosphere (days) as they undergo both dry and wet deposition (Lee *et al.*, 2001).

Methyl mercury may constitute a few percent of the atmospheric mercury - but its source and associated chemistry have yet to be fully demonstrated[38].

Mercury in the Aquatic and Terrestrial Environments

Elemental mercury is oxidised in water to Hg^{2+} in the presence of oxygen, a process enhanced by the presence of organic substances in the aquatic environment. Bivalent mercury can react in a number of ways in the aquatic environment, such as:

- formation of HgS in anaerobic conditions in the presence of hydrogen sulphide;
- reaction to form elemental mercury, which is then readily lost to the atmosphere, thought to be a key process in natural loss to air through degassing[39]; and
- reaction to form methyl mercury via biochemical processes (WHO, 1976).

Methyl mercury is key species of interest for the current study, due to its greater potential for entry into food chains and subsequent bioconcentration, as compared to elemental or inorganic mercury. It is also the most toxic form of mercury. Methyl mercury is formed naturally in the environment, mainly in the freshwater and marine sediments, although it may also be formed in the water column (WHO, 1990). A wide range of microorganisms is capable of methylating mercury, including some soil organisms in addition to those in the aquatic environment.

In the terrestrial environment, the majority of mercury present is in inorganic form with relatively less organic mercury than in the aquatic environment.

4.3.2 Uptake of Mercury by Organisms

In the aquatic environment, mercury is taken up readily by invertebrates and by fish, with accumulation in the former being greater than in the latter. Organic mercury and salts of bivalent mercury can be readily taken up by organisms in the aquatic and terrestrial environment. Generally, organic mercury is taken up more readily than inorganic mercury and is also released more slowly.

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38 One suggested source is landfills, see Lindberg SE *et al.* (2001): *Methylated Mercury Species in Municipal Landfill Gas Sampled in Florida, USA*, Atmospheric Environment, 35(Aug):4001.

39 Elemental mercury may also be formed from organomercurial compounds, through chemical or enzymatic cleavage of the carbon-mercury bond.

Values for bioconcentration factors[40] reported in the recent literature range up to several thousand and several tens of thousands for inorganic and organic mercury respectively. It should be noted, however, that the measured bioconcentration ratios are not a result of environmental partitioning (as is the case with many organic chemicals), but rather as a result of biomagnification in the food chain. Bioconcentration factors for use in the current assessment are considered in more detail in Section 5.

Accumulation of mercury in plants is generally far less pronounced than for aquatic organisms, with concentrations in plants generally being significantly lower than those in the soil. Bioconcentration factors may be greater for methyl mercury, as indicated by Gnamuš *et al.* (2000) who report of value of 1.8 in Idrija, near to the former mercury mining complex. Bioconcentration factors may also be higher for certain plant species, such as mushrooms, and Falandysz *et al.* (2002) report BCF values for caps or whole fruiting bodies of mushrooms between 130±78 to 160±120. The value for *Claviata excipulformis*, an inedible mushroom, was 910±330 (Gucia *et al.*, 2002).

It is generally thought that uptake to and concentrations in plants are dictated primarily by soil, rather than air, concentrations. Uptake is limited by the binding characteristics of soil , the solubility of specific compounds and by the physiology of plant roots.

[40] Ratio of the concentration of mercury in the organism to the concentration in the environment or food.

4.4 Measured Levels in the Environment

4.4.1 Overview

Table 4.1 details the concentrations of mercury in each of the major environmental compartments.

Table 4.1: Mercury Levels in the Environment

Compartment	Levels (measured as mercury)		
	Typical Global[1]	**rural Netherlands[2]**	**Elsewhere**
Air	1 - 4 ng/m^3 (rural) 20 - 50 ng/m^3 (urban)		1.5 - 2.0 ng/m^3 (UK[3])
Soil	0.03 - 0.15 mg/kg dw	0.3 mg/kg dw	rural: 0.03-0.06 mg/kg urban: 0.09-0.16 mg/kg (means, Germany[4]) 0.033-0.058 mg/kg (Polish regions[5])
Ground Water (>10m depth)	0.5 - 15 ng/l	50 ng/l	98% sites < 100 ng/l[4]
Surface Water	0.01 - 6 ng/l (dissolved - rivers) 2 - 12 ng/l (dissolved - lakes) 0.04 - 0.8 ng/l (methyl mercury - lakes)	10 ng/l (dissolved) 60 ng/l (total)	
Sediment	0.2 - 0.4 mg/kg dw	0.3 mg/kg dw	mean: c0.3 mg/kg[4] main river/lake means: <0.05 - 0.28 mg/kg[5]
Sea Water	0.05 - 3 ng/l		0.2 - 4 ng/l (North Sea[6])
Marine Sediment	0.2 - 0.4 mg/kg dw		

Sources:
1) *OECD (1995): Risk Reduction Monograph No. 4 - Mercury*
2) *VROM (2001): Environmental Quality Standards in the Netherlands*
3) *Lee et al. (2000): Sources, Sinks and Levels of Atmospheric Mercury in the UK*
4) *German submission to UNEP (2001)*
5) *Central Statistics Office (2000) supported by a detailed review of Polish scientific literature from the 1990s*
6) *OSPAR (2000)*

4.4.2 Atmospheric Levels

Background mercury levels across Europe are generally in the range 1.3 - 2.1 ng/m^3. As would be expected the levels tend to be higher (by an order of magnitude or more) in industrial areas and in areas close to emission sources such as smelters and chlor-akali plants (EC, 2001b and Lee *et al.*, 2000). Generally, elemental mercury accounts for more than 90% of the total mercury present whilst organic mercury accounts for less than 2% (EC, 2001b).

Currently, there are inadequate data to robustly demonstrate how atmospheric levels of mercury are changing over time. However, given the recent suggestions that anthropogenic sources dominate the global emissions of mercury and that these are now reducing (see S4.2.2), it would be expected that this would be reflected in

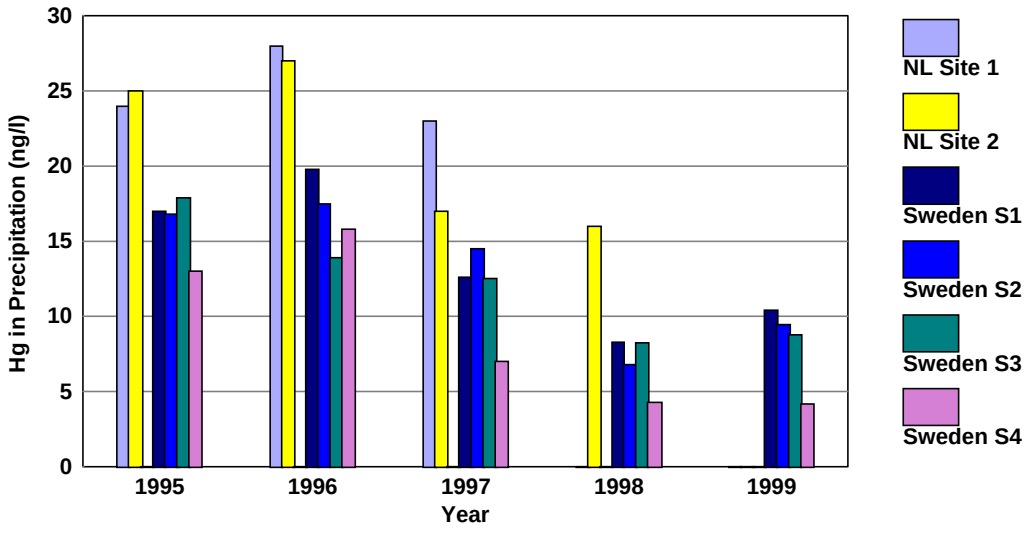
environmental measurements. Evidence of an increased mercury flux to the atmosphere over the past 100 years or so has been found in the Arctic by the Arctic Monitoring and Assessment Programme (AMAP). These findings were one of the main drivers for the establishment of UNEP's Global Mercury Assessment (AMAP, 2001).

Until relatively recently, there have been few instruments capable of measuring the range of mercury forms present in the atmosphere. As a result, there would appear to be no comprehensive long term monitoring records.

Within the UK, particulate phase mercury (i.e. bivalent forms bound to fine particulate matter) which accounts for less than 10% of the total atmospheric mercury has been monitored at a number of sites since the early 1970s. It should be noted that particulate phase mercury tends to be associated with coal combustion (both in power stations and in the home - EC, 2001b). The monitoring results (Lee *et al.*, 2000) indicate fluctuating levels over the period from the early 1970s to around 1990 but neither an upward nor downward trend - although there is a noticeable peak in 1983/84.

Although the data are far from conclusive, there is other evidence to suggest that the reduction in EU mercury emissions is now being reflected in atmospheric mercury levels. Monitoring data for mercury levels (annual averages) in precipitation from two sites in the Netherlands (NL Sites 1 & 2) and four sites in Sweden (Sweden S1 - S4) (from RIVM, 1999 and EC, 2001b respectively) are shown in Figure 4.1.

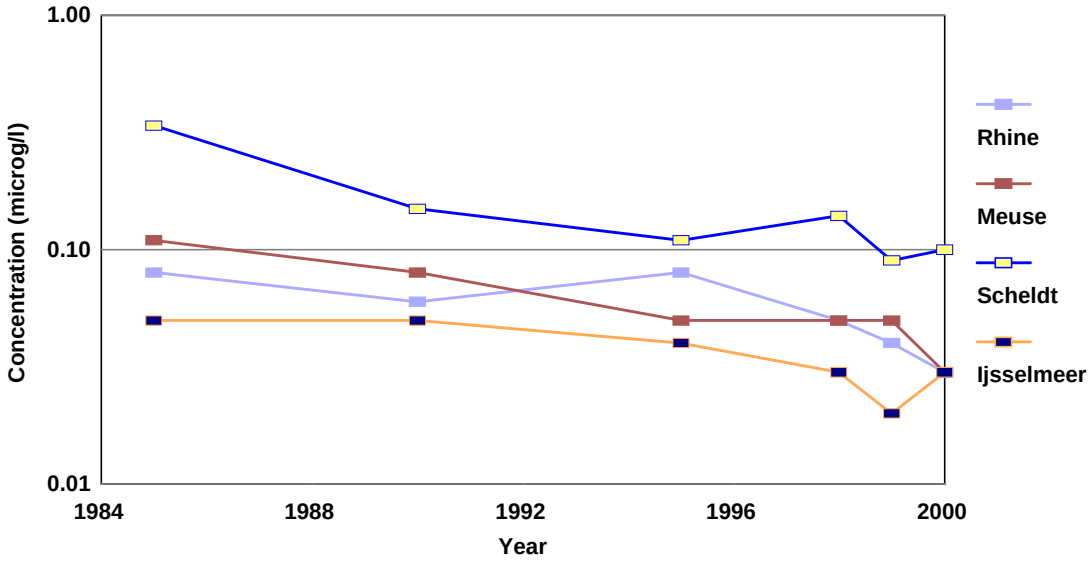
Figure 4.1: Hg Levels in Precipitation in the Netherlands and Sweden



4.4.3 Levels in the Aquatic Environment

As for levels in the atmosphere, there are few data sets which can be used to show changes of mercury levels over time. However, data from the Netherlands (RIVM, 2001) indicate a reduction in fresh water concentrations in recent years as shown in Figure 4.2.

Figure 4.2: Hg Levels in Freshwater in the Netherlands (90%ile Values)



In relation to the presence of methyl mercury in the aquatic environment, extensive monitoring in the 80km of river from the Idrija mine to the Gulf of Trieste (Horvat *et al*., 2000) shows methyl mercury levels in the range 0.02 - 0.6 ng/l which correspond to about 0.5% of the total mercury concentrations (ranging from 3 to >300 ng/l at the mine). Similarly, in the Everglades in Florida, methyl mercury has been found to contribute from <0.2% to 2% of the total mercury content in sediments (Gilmour *et al*., 1998). However, in lakes, the relative concentrations may well be higher - as the USEPA (2001) reports that methyl mercury accounts for 10% of the mercury present.

Levels in Fish

As already noted, most mercury present in the aquatic environment is of the inorganic bivalent form. However, the bioconcentration of methyl mercury tends to lead to relatively higher concentrations in fish (and other aquatic organisms) - particularly amongst fish at the top of the food chain (such as sharks). Levels of mercury in fish may be of the order of 0.1 mg/kg wet weight and this is usually associated with methyl mercury.

4.4.4 Levels in the Terrestrial Environment

Most terrestrial mercury is in the form of inorganic salts with minimal organic mercury present. Typical concentrations in soil are of the order of 0.1 mg Hg/kg dry weight (dw). As would be expected there are reports of much higher concentrations

on contaminated industrial sites and mean values of 2.5 mg/kg and 0.065 mg/kg have been reported for total mercury and methyl mercury respectively in the Idrija area of Slovenia, near to the mine-smelter area (Gnamuš *et al*, 2000). Similarly, the German submission to UNEP reports high localised concentrations at sites which used to impregnate telegraph poles, railway sleepers, etc. with mercuric chloride.

Levels in Plants & Food

Typical mercury levels in plants are less than <0.1 mg Hg/kg fresh weight as illustrated by crop samples listed in Table 4.2. Higher concentrations are again reported in contaminated areas, such as in Almaden (Spain) near to the mercury mine, where concentrations in vegetation of over 100 mg/kg were reported in the 1980s (WHO, 1989).

Table 4.2: Mercury Levels in Crops (mg/kg fresh weight)

Crop	UK[1]	Poland[2]
Fresh Fruit	0.0006 (mean)	0.0001 - 0.0134 (max)
Green Vegetables	0.0004 (mean)	0.0001 - 0.0039 (max)
Potatoes	0.0010 (mean)	0.0001 - 0.0030 (max)
Other Vegetables (eg Carrots)	0.0006 (mean)	0.0001 - 0.0058 (max)
Cereals	0.0040 (mean)	0.0001 - 0.0070 (max)

Sources: 1) MAFF (1999) and 2) CSO (2000)
Note that 1 mg/kg is equivalent to 1 part per million

4.5 Human Exposure

4.5.1 Overview

For typical citizens of the EU and the three accession countries, uptake of mercury is dominated by inhalation of vapours from dental amalgam and by ingestion of foodstuffs (particularly fish). As would be expected, exposure is greater where past industrial activities have led to significant mercury emissions to the environment.

4.5.2 Non-Occupational Exposure

Typical mercury intakes within the EU (and three accession countries) are of the order of 10 µg/day as shown in Table 4.3.

As can be seen from Table 4.3, a significant contribution to the human uptake of mercury is associated with dietary intake of fish (and fish products). In view of this, the EU has established a maximum mercury content of 0.5 mg/kg (wet weight) for 'fishery products' with a higher limit of 1 mg/kg for a range of specified fish species[41].

[41] As specified in Commission Regulation (EC) No. 466/2001 **Setting Maximum Levels for Certain Contaminants in Foodstuffs** dated 8 March 2001 (as amended by Commission Regulation (EC) No. 221/2002 dated 6 February 2002).

Table 4.3: Daily Uptake of Mercury by Humans			
Pathway	**Global[1]**	**UK Data[2]**	**Europe[3]**
Direct Inhalation	negligible	negligible	< 0.2 µg/day
Inhalation of Dental Amalgam Vapours	3 - 17 µg/day	1 - 10 µg/day	3 - 17 µg/day
Dermal Absorption	negligible	negligible	negligible
Ingestion of Foodstuffs (excluding fish products) - ***mainly as inorganic salts***	0.25 µg/day	1-2 µg/day	0.36 µg/day
Ingestion of Fish Products - ***mainly as methyl mercury***	could be >100 µg/day	>5 µg/day for some	2.3 µg/day
Sources: 1) OECD (1995): Risk Reduction Monograph No. 4 - Mercury; 2) Based on Lee et al. (2000); and 3) WHO (2000): Air Quality Guidelines - Mercury.			

Mercury levels in blood and urine provide are often used as (short term) 'biomarkers' for mercury intake while hair provides a proven (long term) guide to methyl mercury intake. Detailed data on mercury levels in blood in the Czech Republic have been provided[42]. The median for 1,207 adults was found to be 0.78 µg/l with a range of 0.01 - 7.13 µg/l. The median for 764 children was slightly lower at 0.46 µg/l but with a very similar range. Similar values are reported for Germany (German submission to UNEP, 2001) with median values of 0.6 and 0.4 µg/l and 95% values of 2.1 and 1.4 µg/l amongst 3,958 adults and 712 children respectively. The corresponding median value of mercury in urine was 0.5 µg/l (with a 95% value of 3.9 µg/l) for both children and adults. ATSDR (1999) reports similar levels amongst the general US population and that elevated mercury levels in blood of 109 µg/l have been found amongst women using skin-lightening creams (as discussed in S3.7.8). Similar elevated levels have been found in amongst those eating contaminated fish and amongst workers (see below).

4.5.3 Occupational Exposure

As would be expected, occupational exposures are somewhat greater than 'typical' general population exposures due to greater environmental concentrations. By way of example, atmospheric mercury levels of 300 ng/m^3 are still measured around the abandoned Idrija mine (compared to 1-2 ng/m^3 typical background levels).

Data from mercury miners and workers in a range of industries (including chlor-alkali works, lamp manufacture, thermometer manufacture, metal processing, etc.) provide useful indicators to the human toxicity of mercury. In broad terms, chronic exposure to mercury levels in the workplace above 0.1 mg/m^3 were found to lead to classic symptoms of mercury poisoning (tremors, mental disturbance, etc.) in a range of studies from the 1930s through to 1970 (WHO, 1976). Such studies have led to increased controls on occupational exposure.

However, the key data on the effects of exposure to mercury and its compounds were derived from studies on the consumption of foodstuffs with elevated levels of mercury and, more importantly, methyl mercury as discussed in Section 6.3.

[42] The data are also published: Central European Journal of Public Health, Vol 8 #2, pp 117-119 (2000).

5. CALCULATIONS OF PREDICTED ENVIRONMENTAL CONCENTRATIONS (PECS)

5.1 Introduction

The *EUSES* software model generates predicted environmental concentrations (PECs) based on estimated releases on all spatial scales which are derived from the use patterns and substance properties.

In order to undertake the analysis, *EUSES* considers emissions associated with production, formulation, processing, private use and recovery. Some of these aspects have been considered in Section 3 and these provide a robust basis for estimation of release factors. Therefore, default values indicated by the Technical Guidance Document (European Commission, 1996) have been substituted, where appropriate, with calculated emission factors. The emission factors used in the *EUSES* analysis are summarised in the subsections below.

Modelling the behaviour of mercury emissions is not straightforward as the initial release is usually in the form of elemental mercury which becomes inorganic mercury in the environment. A portion may then be methylated to form methyl mercury - particularly in the aquatic compartment. As indicated in Section 4, methyl mercury may make up to 10% of the mercury present (particularly in lakes) - which will be taken as a worst case scenario in the analysis which follows.

This section concludes with a description on the use of *EUSES* and a summary of the PEC results together with an associated commentary.

5.2 Production

The 'production' step has been taken as the collection and refining of mercury from a gas (or vapour) stream after heating ore (mercury or other non-ferrous metal) or recovered mercury-containing items. All mercury production sites (whether primary or secondary) are covered by the requirements of IPPC. Recent guidance (European Commission, 2001a) suggests 1997 emission factors of:

- primary production: 0.01 to air; 7.8×10^{-6} to water; and 0 to waste; and
- secondary production: 2×10^{-6} to air; 3×10^{-7} to water; and minimal solid waste.

Clearly, the impact of the primary production emission factor to air could have a significant impact on the analysis. A much lower figure may be appropriate given the IPPC requirements. It is worth noting that MAYASA claim[43] an overall emission factor of less than 0.00l.

[43] Lopez FA *et al*. (2000): **Considerations on the Implementation of IPPC and the Primary Mining of Mercury**, CSIC (National Centre of Mining, Spain) Report 2399 prepared on behalf of MAYASA and submitted to European IPPC Bureau.

A further indication of lower emission factors is provided by the Finnish zinc processing plant. The Kokkola plant produces about 225,000 t/year of zinc and about 65 t/year of mercury. The zinc ore is roasted which drives off the mercury which is then cleaned from the gas stream using sulphuric acid. The precipitate is mixed with lime and heated to 700^{o}C to distil off the metallic mercury vapour. The associated emissions to the environment are estimated to be less than 10 kg/year to air and 3 kg/year to water (sea) (Finnish Environment Institute, 1999). These figures correspond to emission factors of $<1.5 \times 10^{-4}$ to air and 4.6×10^{-5} to sea.

In relation to secondary production (which includes the refining of mercury from chlor-alkali plants), consultation suggests that the above figures of a few grammes per tonne[44] of mercury can be achieved and are consistent with the BAT requirements (essentially enclosed handling and scrubbing of ventilation gases).

The *EUSES* model requires the use of emission factors for emissions to the air, wastewater, surface water and industrial soil. The above figures account for on-site wastewater treatment and there is no discharge to industrial soil. Solid waste residues (including waste water sludges/residues) are generally returned to the furnace. Residues requiring off-site disposal will be sent directly to engineered landfills.

Table 5.1 summarises the emission factors used for the production of mercury.

Table 5.1: Release Fractions for Mercury Production used in EUSES Modelling

Production Route	Fraction of tonnage released to	Value	Source & Comment
Primary Mined Production	Air	0.001	Report for MAYASA
	Wastewater	0	Emissions processed on site
	Surface Water	4.6×10^{-5}	Although EC (2001a) data suggest lower figure, source uncertain. Higher value derived for 'by-product' production used
	Industrial soil	0	No discharge to land
By-product of other Non-Ferrous Primary Production	Air	1.5×10^{-4}	Finnish Environment Institute (1999)
	Wastewater	0	Emissions processed on site
	Surface Water	4.6×10^{-5}	Finnish Environment Institute (1999)
	Industrial soil	0	No discharge to land.
Secondary Production	Air	2×10^{-6}	EC (2001a), supported by consultation
	Wastewater	0	Emissions processed on site
	Surface Water	3×10^{-7}	EC (2001a), supported by consultation
	Industrial soil	0	No discharge to land (minimal solid waste to landfill)

For the purposes of the analysis which follows it has been assumed that these emission factors should be applied to the total current EU consumption of mercury in the products under study - i.e. 119.2 tonnes. Whilst it is recognised that some products are imported (e.g. thermometers), it is possible that the mercury used will have originated in the EU.

[44] Note that an emission factor of 1×10^{-6} corresponds to an emission of 1 g per tonne produced.

It is further assumed, in the absence of detailed evidence of the sources of mercury used in the products under study, that the production quantity will be divided equally amongst primary production, by-product production and secondary production - i.e. 39.7 t per production route.

5.3 Formulation and Processing (Product Manufacture)

5.3.1 Dental Amalgam

It has been assumed that, generally, no 'formulation' stage is involved in the manufacture of the various products under study. Instead, product manufacturing operations are considered to take place at the 'processing' stage where mercury is used and processed along with other substances in order to produce the end products which are then forwarded to the consumers. The exception is that mercury used in dental amalgam must be of the highest quality and may be re-refined (through triple distillation) prior to 'processing'. It would be expected that the emission factors would essentially be the same as for 'secondary production' (see Table 5.1). Limited data from consultation suggest only minor atmospheric emissions and for the purposes of this analysis, the same factors will be used as those shown in Table 5.1.

For this analysis it has been assumed (conservatively) that the current EU consumption of mercury used in dental amalgam (70 t/year) is formulated within the EU and that, as discussed in S3.2.4, the 'formulator' provides pre-packed mercury for the use by the 'processor'. As such it has been assumed that there are no emissions associated with 'processing' (i.e. packaging the mercury with the other amalgam materials). The associated emission factors are shown in Table 5.2.

Table 5.2: Release Fractions for Dental Amalgam used in EUSES Modelling

Process Step	Fraction of tonnage released to	Value	Source & Comment
Formulation	Air	2×10^{-6}	EC (2001a), supported by consultation
	Wastewater	0	Emissions processed on site
	Surface Water	3×10^{-7}	EC (2001a), supported by consultation
	Industrial soil	0	No discharge to land (minimal solid waste to landfill)
Processing	All media	0	Zero emissions assumed

5.3.2 Other Products

For batteries and other products, the default *EUSES* emission factors have been overridden and replaced with emission factors adapted from the estimates presented in the WS Atkins report (1998) on product manufacture emissions. It should be noted that attempts to obtain more site-specific data to refine these figures have not been successful. It has been assumed that all solid waste arisings from product manufacturing facilities (i.e. for batteries, lamps, etc.) are disposed of to landfill (as opposed to a portion going to incinerators as would occur with municipal waste). Given that the mercury used in product manufacture will tend to be in elemental form,

it has been assumed that 9.5% of the mercury disposed to landfill will be released to atmosphere (using the same approach as used in Section 3.5.4). By way of example, a solid waste stream of 140 g waste per kg of mercury used would lead to atmospheric emissions of 13.3 g/kg which is equivalent to emission factor of 0.0133.

No emission estimates are given in the WS Atkins report with regard to batteries manufacture. It has been assumed that the emissions from manufacture will be similar to those for the electronics industry as in both cases, production essentially entails the incorporation of a small amount of mercury into the product. The emission factors used in 'processing' are summarised in Table 5.3.

Table 5.3: Release Fractions for 'Processing' used in EUSES Modelling

Product Manufacture	Fraction of tonnage released to	Value	Source & Comment
Batteries and Electrical Control & Switching Equipment	Air (plant)	3.0×10^{-7}	Based on WS Atkins (1998) with additional landfill emissions
	Air (landfill)	4.75×10^{-4}	
	Wastewater	3×10^{-5}	Based on WS Atkins (1998)
	Surface Water	0	Discharges to water and soil associated with sewage treatment plant discharges (calculated by EUSES)
	Industrial soil	0	
Lamp Production	Air (plant)	0.022	Based on WS Atkins (1998) with additional landfill emissions
	Air (landfill)	1.33×10^{-2}	
	Wastewater	3×10^{-5}	Based on WS Atkins (1998)
	Surface Water	0	Discharges to water and soil associated with sewage treatment plant discharges (calculated by EUSES)
	Industrial soil	0	
Measuring & Control Equipment	Air (plant)	3.0×10^{-7}	Based on WS Atkins (1998) with additional landfill emissions
	Air (landfill)	1.33×10^{-2}	
	Wastewater	3×10^{-5}	Based on WS Atkins (1998)
	Surface Water	0	Discharges to water and soil associated with sewage treatment plant discharges (calculated by EUSES)
	Industrial soil	0	

These emission factors are applied to the quantities of mercury used in the manufacture of products within the EU. For most of the products listed in Table 5.3, there are significant imports and, in some cases, exports as illustrated in Table 5.4. Based on the discussions presented in Section 3 for each of the product groups, estimates have been made as to the likely quantities of mercury used in product manufacture within the EU (as opposed to the quantities consumed (i.e. sold) in the products within the EU). Clearly, such estimates carry a degree of uncertainty.

Table 5.4: Quantities of Mercury used in EU Product Manufacture			
Product	**Tonnes of Hg/year used in EU for**		**Comment**
	Consumption	**Production**	
Batteries	8.0	3.0	As discussed in Section 3.3, although batteries are imported and exported in similar quantities, most of the mercury consumed is likely to be associated with imported zinc mercury cells
Lamp Production	5.2	5.2	Lamps are both imported and exported. As shown in Table 3.16 and Figure 3.4, most mercury is associated with double-ended fluorescent tubes which appear to be imported and exported in similar quantities.
Measuring & Control Equipment	28	8.0	As discussed in Section 3.5, it would appear that most measuring equipment is now imported
Electrical Control & Switching Equipment	8.0	4.0	As discussed in Section 3.6.3, a significant portion of mercury switches are now imported

5.4 Private Use and Recovery of Mercury in Products

The emission factors which were calculated in Section 3 for each of the products under study were carried forward to the *EUSES* analysis. Since *EUSES* requires inputs to atmosphere, wastewater, surface water and industrial soil, a degree of backtracking was required for 'dental amalgam' and 'measuring and control equipment' in order to generate values for release fractions to waste water[45].

The calculations in Section 3 have also taken into account any recovery and recycling issues within each of the application categories. Where recovery takes place (with subsequent re-use of mercury), this has been incorporated in the respective flowchart and the emission calculations have been adjusted. Therefore, the 'recovery' life cycle step has not been included in the *EUSES* modelling as the effects are taken into account in the 'private use' step.

Table 5.5 summarises the emission factors for releases during 'private use' of mercury-containing equipment. In each case, the values have been based on emissions per tonne (of current consumption) used in the EU. It should be noted that these figures account for emissions associated with the disposal of 'old' products and equipment. As discussed in Section 3, this 'disposal' stream may be significantly greater (in terms of mass flow rate) than the current consumption since the usage of mercury is declining in some sectors.

[45] In essence and with reference to Figures 3.1 and 3.6, emissions 'downstream' of sewer were not used and the input to sewer was used as the input to wastewater for *EUSES.*

Table 5.5: Release Fractions for 'Private Use' used in EUSES Modelling			
Product Manufacture	**Fraction of Tonnage Released to**	**Value**	**Source & Comment**
Dental Amalgam	Air	0.0702	Based on Section 3.2 calculations (adjusted to account for discharges to wastewater)
	Wastewater	0.0762	
	Surface Water	0	
	Industrial soil	0	
Batteries	Air	0.0612	Based on Section 3.3 calculations
	Wastewater	0	
	Surface Water	0	
	Industrial soil	0	
Lamps	Air	0.1388	Based on Section 3.4 calculations
	Wastewater	0	
	Surface Water	0	
	Industrial soil	0	
Measuring & Control Equipment	Air	0.2436	Based on Section 3.5 calculations (adjusted to account for discharges to wastewater)
	Wastewater	0.0182	
	Surface Water	0	
	Industrial soil	0	
Electrical Control & Switching Equipment	Air	0.2554	Based on Section 3.4 calculations
	Wastewater	0	
	Surface Water	0	
	Industrial soil	0	

5.5 Predicted Environmental Concentrations

5.5.1 Introduction

The *EUSES* model was used to generate PECs which when combined with toxicity data (as discussed in Section 6) enabled the risks to the environment and to humans to be characterised. This exercise was undertaken for the main product groups used in the EU. At the outset, it must be emphasised that the behaviour of mercury and its compounds does not lend itself to analysis using the *EUSES* model and the results generated must be treated with a degree of caution.

5.5.2 Approach to *EUSES*

Emissions from the different types of mercury production sites (primary production in Spain, production from non-ferrous metal primary production and secondary production) were considered separately. It was assumed that each of the three mercury production routes produced 39.7 t/year of mercury (to give a combined figure of 119.2 t/year which is the EU consumption of the products under study).

Product manufacture was modelled for each of the five main product groups data under study to give a further five scenarios. In order to account for the degree of imports associated with batteries, measuring equipment and electrical equipment, the runs were based on the quantities of mercury used in EU product manufacture

(assumed to be 3, 8 and 4 t/year respectively). For all the product manufacture activities (bar dental amalgam), it was necessary to account for both local plant losses and atmospheric losses associated with the disposal of solid waste.

Finally, the 'private use' of each product group was also modelled (using the total consumption figures). The listing of the modelled 'use patterns' is shown in Table 5.6.

Table 5.6: Use Patterns Modelled with *EUSES*

Use Pattern	Modelling Stage	Mercury Emissions Modelled
1. Production	Production	From primary production
	Formulation	From non-ferrous by-products
	Processing	From secondary production
2. Dental Amalgam	Formulation	From re-refining mercury to be used in dental amalgam
	Private Use	From use and disposal of dental amalgam (as described in S3.2)
3. Batteries	Formulation	From plants producing batteries within EU
	Processing	From disposal of plant waste (see Table 5.3)
4. Batteries	Private Use	From use and disposal of batteries (as described in S3.3)
5. Lighting	Formulation	From plants producing lamps within EU
	Processing	From disposal of plant waste (see Table 5.3)
	Private Use	From use and disposal of lamps (as described in S3.4)
6. Measuring Equipment	Formulation	From plants producing measuring equipment within EU
	Processing	From disposal of plant waste (see Table 5.3)
7. Measuring Equipment	Private Use	From use and disposal of measuring equipment (as described in S3.5)
8. Electrical Equipment	Formulation	From plants producing electrical equipment within EU
	Processing	From disposal of plant waste (see Table 5.3)
9. Electrical Equipment	Private Use	From use and disposal of electrical equipment (as described in S3.6)

Note: Since EUSES can model a maximum of ten 'use patterns', it was necessary to combine some 'uses' into a single 'use pattern' by adapting some of the modelling steps.

The *EUSES* model was run twice:

- Run 1: 100% of emissions considered to be as elemental mercury; and
- Run 2: 100% of emissions considered to be as inorganic mercury (mercuric chloride).

Although attempts were made to extend *EUSES* to organic mercury, the analysis was considered to be rather tenuous (since organic mercury is not released but forms in the environment). Instead, consideration is given to using the PECs for inorganic mercury as a basis on which to estimate the potential PECs for organic mercury.

5.5.3 Properties Used

As noted in the TGD (EC, 1996), care must be taken when applying *EUSES* to metals and their compounds. *EUSES* requires basic data on the properties of the mercury compounds (as presented in Section 2) and these were entered. However, the 'flow' of mercury through the environment is complex and a number of further data points and assumptions were required as outlined below.

Partition Coefficients

EUSES estimates partition coefficients from log K_{ow} (the octanol-water partition coefficient). However, such methods are not directly applicable to metals (and their compounds) and, as a result, specific values for each of the partition coefficients must be provided. These specific values are based on theory and/or observations. A listing of those values used in *EUSES* for elemental and inorganic mercury is presented in Table 5.7.

Table 5.7: Partition Coefficients used in EUSES Modelling

Compound	Partition Coefficient	Value	Source & Comment
Elemental Mercury	Henry's Law constant (air-water)	680 $Pa.m^3/mole$	A range of values was found including around 500 (USEPA, 1997); 700 (Sunderland & Gobas, 2001); 720 (INERIS, 2000); and 860 (PhysProp data-base[1]). A geometric mean value was selected
	Solids-water in suspended sediment and sediment	126,000 l/kg (log K = 5.1)	The same values were used as derived for inorganic mercury
	Solids-water in soil	1,000 l/kg	Value quoted in INERIS, 2000
Inorganic Mercury	Henry's Law constant (air-water)	680 $Pa.m^3/mole$	Wide ranging values were found from 0.32 (PhysProp data-base) to 3.6×10^{-5} (INERIS, 2000). However, the value for elemental mercury was used since, in practice, >90% of atmospheric mercury is elemental and it takes time for the elemental mercury convert to its bivalent state (see, for example, Lee *et al*., 2000 and EC, 2001b). Thus, use of this value will more accurately predict the environmental fate following a release (most of which are to atmosphere)
	Solids-water in suspended sediment	126,000 l/kg (log K = 5.1)	Log K values found include 4.9 (Sunderland & Gobas, 2001) and 5.23 (Eurochlor, 1999 & INERIS, 2000). A geometric mean of 5.1 was used
	Solids-water in sediment	126,000 l/kg (log K = 5.1)	The same K values tend to be used for this and the SS-water partition coefficients. Hence, the same value was used
	Solids-water in soil	60,000 l/kg (log K = 4.8)	Values quoted in INERIS (2000) range from 6,800 - 60,000 and the highest value was used.

Data-base sources:

1) SRC PhysProp Database on http://escsyrres.com/interkow

2) Hazardous Substances Data Base on http://toxnet.nlm.nih.gov

Vapour Pressures

The true vapour pressures for mercury and mercuric chloride were used since a (minimal) degree of evaporation would be expected. The values were 0.267 Pa and 0.1 Pa respectively - although these were not used by *EUSES* to derive Henry's Law constants.

Aerosol Particles

A feature of inorganic mercury is that a significant proportion is bound to particles in the atmosphere which are deposited more rapidly than elemental mercury. For the purposes of this analysis a value of 9% was selected which is consistent with observations reported by Lee *et al.* (2000) and EC (2001b).

Bio-concentration

To reflect the importance of bio-concentration in fish, a bio-concentration factor (BCF) of 5,000 for inorganic mercury was used. A BCF value of 50,000 was used for organic mercury in later stages of the analysis. These values are towards the higher end of the ranges suggested by ATSDR (1999) and INERIS (2000).

5.5.4 PECs - Air Compartment

For the air compartment, the values derived from using elemental mercury were used. The results are summarised in Table 5.8.

Table 5.8: PEC Values for Air (ng/m^3) for Mercury & Products

Parameter	Value	Comment
Typical measured value in EU	1.3 - 2.1	See Section 4.4.2
Continental PEC associated with manufacture and use of mercury in products under study	0.10	This represents about 5-10% of typical EU levels
Regional PEC associated with manufacture and use of mercury in products under study	0.27	For the 'worst' region, this represents 10-20% of typical EU levels
Local PEC values associated with mercury production:		
Primary production (Spain)	30.5	Level significantly above 'background'
Production from non-ferrous by-products	1.18	
Secondary production	0.30	
Local PEC values associated with product manufacture:		
Dental amalgam	0.28	Level marginally above regional PEC value
Batteries	0.28	Ditto - note that level is associated with landfill emissions rather than from plant
Lamps	3.62	
Measuring equipment	1.28	Levels are associated with landfill emissions rather than from plant
Electrical equipment	0.31	

Overall, the use of mercury in the products under study, the associated product manufacture as well as the associated production of mercury make, as would be expected, a minor contribution to mercury in air concentrations at continental and regional levels.

In terms of 'local' concentrations, the PEC values are dominated by those associated with the primary production of mercury in Spain. Otherwise, the PEC values tend to be within the 'typical' range of values found in the EU although those for lamp manufacture are slightly higher, due primarily to the relatively high air emission factor used (see Table 5.3). As noted in Table 5.8, the PEC values for some of the product manufacture sites are associated with subsequent losses to atmosphere from solid waste disposal rather than from the product manufacturing site itself.

5.5.5 PECs - Soil Compartment

For the soil compartment, the values derived from using inorganic mercury were used. The results are summarised in Table 5.9.

Table 5.9: PEC Values for Soil (µg/kg dw) for Mercury & Products

Parameter	Value	Comment
Typical measured value in EU	50 - 100	See Section 4.4.4 & Table 4.1
Continental PEC associated with manufacture and use of mercury in products under study	1.63	This represents a few % of typical EU levels
Regional PEC associated with manufacture and use of mercury in products under study	4.34	For the 'worst' region, this represents 4 - 8% of typical EU levels
Local PEC values[1] associated with mercury production:		
Primary production (Spain)	6.18	Values essentially close to 'regional' PEC value - although higher around the primary production site
Production from non-ferrous by-products	4.66	
Secondary production	4.61	
Local PEC values[1] associated with product manufacture:		
Dental amalgam	4.61	Values essentially close to 'regional' PEC value
Batteries	4.61	
Lamps	4.78	
Measuring equipment	4.66	
Electrical equipment	4.61	
Note: 1) Local values based on agricultural PEC averaged over 180 days		

As can be seen the scenarios considered make a minor contribution to mercury in soil concentrations at continental and regional levels. Furthermore, there is very little 'local' effect on soil concentrations associated with emissions from mercury production and product manufacture facilities.

This findings appear consistent with the emissions to 'soil' being much lower than those to atmosphere (see Table 3.29).

5.5.6 PECs - Aquatic Compartment

Water

For the water compartment, the values were first derived for inorganic mercury using *EUSES*. As a 'worst case' estimate, it was assumed that the organic mercury concentration would be 10% of the inorganic concentration (as this is an upper limit of that observed in the aquatic environment). The associated results are summarised in Table 5.10.

Table 5.10: PEC Values for Water (ng/l - dissolved) for Mercury & Products

Parameter	Value		Comment
	Inorganic	Organic	
Typical measured value in EU	1 - 10	<10% of inorganic	See Table 4.1 & Section 4.4.3
Continental PEC associated with manufacture and use of mercury in products under study	0.03	0.003	This represents perhaps 1% of typical EU levels
Regional PEC associated with manufacture and use of mercury in products under study	0.64	0.064	For the 'worst' region, this represents a significant fraction of typical EU levels
Local PEC values associated with mercury production:			
Primary production (Spain)	0.64	0.064	Values the same as 'regional' PEC value (due to minimal discharges to water)
Production from non-ferrous by-products			
Secondary production			
Local PEC values associated with product manufacture:			
Dental amalgam	0.64	0.064	Values very close to 'regional' PEC value (due to minimal discharges to water)
Batteries	0.69	0.069	
Lamps	0.67	0.067	
Measuring equipment	0.67	0.067	
Electrical equipment	0.67	0.067	

Overall, a similar pattern emerges as for the air and soil compartments. Contributions to continental and regional concentrations are dominated by product use. The contributions of the various product groups are dominated by those associated with dental amalgam and measuring equipment due to their higher levels of emission (see Table 3.29).

As for the soil compartment, there is very little 'local' effect on water concentrations associated with emissions from production and product manufacture facilities.

Sediment

For sediments (as for the water compartment), the values were first derived for inorganic mercury using *EUSES*. As a 'worst case' estimate, it was assumed that - as for water - the organic mercury concentration would be 10% of the inorganic concentration. The associated results are summarised in Table 5.11.

Table 5.11: PEC Values for Sediment (μg/kg dw) for Mercury & Products			
Parameter	**Value**		**Comment**
	Inorganic	**Organic**	
Typical measured value in EU	300	<10% of inorganic	See Table 4.1 & Section 4.4.3
Continental PEC associated with manufacture and use of mercury in products under study	4.2	0.42	This represents about 1% of typical EU levels
Regional PEC associated with manufacture and use of mercury in products under study	81	8.1	For the 'worst' region, this represents about 25% of typical EU levels

As before, contributions to continental and regional concentrations are dominated by product use. As for water, the overall significance is of the order of 1% as indicated by the continental concentrations. The results indicate that the 'worst' region may experience sediment concentrations which are about 25% of 'typical' EU levels, which again is consistent with the results for water.

Local PEC values for sediment are calculated by *EUSES* for an 'emission episode' and are not directly comparable to the longer term continental and regional values. The predicted effects of these emission episodes are explored further in Section 7.

5.5.7 Summary

The behaviour of mercury and its associated derivative compounds in the environment is complex. An attempt has been made to account for this behaviour by using *EUSES* for elemental mercury and inorganic mercury (mercuric chloride). As a worst case, the results for organic mercury (methyl mercury chloride) were assumed to be 10% of the inorganic mercury concentrations.

Specific data on partition coefficients were derived - although some of the values are uncertain. However, some assumptions have been made to 'force' the model to reflect reality. In particular, the Henry's Law constant for elemental mercury was applied to inorganic mercury since the balance of loads between the air and other compartments is mainly governed by the behaviour of the elemental mercury released (initially) to the atmosphere.

As already indicated, the results of the modelling are dominated by the emissions associated with product use which total 22.6 t/year (from Table 3.29). For comparison, the corresponding emissions (for the EU-15 and three accession countries under study) from all anthropogenic sources are 161 t/year (from EC, 2001b). Such figures suggest that, whilst there are clearly uncertainties in the results, it would be expected that the environmental concentrations associated with the products under study form a minor part of observed levels in the environment.

6. EFFECTS OF MERCURY

6.1 Overview

Mercury and its compounds are persistent, bioaccumulative and toxic and may pose risks to people and to the environment. The greatest risk to humans and wildlife is associated with the formation of methyl mercury and its bioconcentration in the aquatic food chain (USEPA, 2000).

6.2 Environmental Toxicity

6.2.1 Methodological Considerations

Limited data are presented on environmental toxicity in WS Atkins (1998) and OECD (1995). However, more information on ecotoxicity (NOEC, LOEC, EC_{50}, etc.) by species and compartment is presented by Eurochlor (1999a). Similarly, the French Institut National de l'Environnement Industriel et des Risques has compiled a review of toxicological and environmental data on mercury and its compounds (INERIS, 2000).

The Eurochlor (1999a) and INERIS (2000) documents have been reviewed so as to provide a range and comparison of NOEC values for input into the *EUSES* program (JRC, 1997) which, in accordance with the TGD, requires the selection of the most sensitive results for a range of taxonomic groups.

It is a requirement of the TGD (European Commission, 1996) that the validity of tests and documentation should be taken into account when selecting values. As there is neither the time nor resources in this study to examine source documentation, pre-validated data points from the literature have been used in preference to other data. Both Eurochlor (1999a) and INERIS (2000) documents consider the quality of data points presented[46] and data from these documents have been used in preference.

However, there remains a paucity of data for the terrestrial compartment and NOECs have been supplemented, where necessary, with data from other sources. In relation to the aquatic environment, a review of ecotoxicology data from *AQUIRE* (the USEPA data-base for the aquatic environment) was undertaken and a comparison made with the validated data in Eurochlor (1999a). This found no significant difference in the most sensitive values for this most complete data set (i.e. the aquatic compartment). This provides a degree of reassurance over the use of the data provided in Eurochlor (1999a) and INERIS (2000). A summary of this review is provided in Annex 4.

[46] Eurochlor (1999) ranks sources on the basis of validity. All values appearing in INERIS (2000) have been validated by RIVM (1999): **Environmental Risk Limits in the Netherlands**, RIVM. No. 601640 001, and Slooff *et al.* (1995): **Integrated Criteria Document Mercury**, RIVM. No. 601014 008.

6.2.2 Micro-organisms

The *EUSES* software model requires data on NOECs (No Observed Effect Concentrations) for micro-organisms which could affect the operation of sewage treatment plants. The TGD refers to specific populations to be considered such as *Pseudomonas putida*. INERIS (2000) reports a (geometric) mean NOEC of 11 µg/l for inorganic mercury (based on 6 and 16 hr NOEC values). For organic mercury, INERIS (2000) provides a NOEC of 0.2 µg/l for bacteria (based on an 18 hr NOEC value). These values have been used in the analysis for inorganic (and elemental) and organic mercury respectively.

6.2.3 Aquatic Compartment

Ideally, the TGD and *EUSES* software model require data on long-term NOECs (No Observed Effect Concentrations) for fish, *Daphnia*, algae and other aquatic species. It is considered that there are sufficient NOEC data to provide such information in relation to inorganic and organic mercury in the freshwater environment. For the purposes of this study, we have derived freshwater NOEC values for inorganic mercury (typically mercuric chloride) and organic mercury (typically methyl mercury chloride) as indicated in Table 6.1.

Table 6.1: Aquatic (Freshwater) Data used in *EUSES* Modelling

Inorganic Mercury	**NOEC µg/l**	**Source Document**
NOEC Fish	0.3	INERIS (2000) Geometric mean for *Pimephales promelas* (fathead minnow)
NOEC *Daphnia*	0.7	INERIS (2000) Geometric mean for *Daphnia magna* (water flea)
NOEC Algae	2.5	Eurochlor (1999a) and INERIS (2000) for *Microcystis aeruginosa* (blue-green algae)
NOEC Other aquatic species	0.62	Eurochlor (1999a) for *Hyalella azteca* (an amphipod)
Methyl Mercury		
NOEC Fish	0.07	INERIS (2000) for *Pimephales promelas* (fathead minnow)
NOEC *Daphnia*	0.09	INERIS (2000) and Eurochlor (1999a) for *Daphnia pulex* (water flea)
NOEC Algae	1	No direct data, so used 'marine' value from Eurochlor (1999a) for *Laminaria saccharina* (oarweed)
NOEC Other aquatic species	0.03	Eurochlor (1999a) for *Dugesia dorotocephala* (turbellarian flatworm)

Fuller information on the sources, test duration and associated end-points (where available) is presented in Table 6.2 for inorganic and organic mercury in the freshwater environment. Since it is understood that marine environmental risk assessments will be required when the revised TGD (currently in draft form) is formally adopted, further data on the marine environment have been presented. As can be seen, there are relatively fewer marine data for organic mercury but it would appear that the NOEC values for the two environments are broadly comparable.

Table 6.2: Summary of NOECs for Aquatic Organisms						
Group	**Mercury Form**	**Marine Data NOEC µg/l**		**Freshwater Data NOEC µg/l**		**Source[1]**
Fish	inorganic mercury	10	*Fundulus heteroclitus* (mummichog) - Sharp & Neff, 1980 (32d - hatching success)	0.68 - 1	Low: Geometric Mean - *Pimephales promelas* (fathead minnow); low [0.5] based on Snarski & Olson, 1982 (41 wk - growth & reproduction) High: *Brachydanio rerio* (zebra fish) - Dave & Xiu, 1991 (14d - mortality)	Eurochlor
		10	*as above*	0.3	Geometric Mean – *Pimephales promelas* (fathead minnow); low [0.09] based on Snarski & Olson, 1982 (30d - growth of progeny)	INERIS
	methyl mercury	no data		0.15 - 29	Low: Geometric Mean - *Salvelinus fontinalis* (brook trout); low value [0.08] - Christensen, 1975 (248d - growth of larvae) High: *Oncorhynchus kisutch* (coho salmon) - Devlin & Mottet, 1992 (48d - embryo mortality)	Eurochlor
		no data		0.07	*Pimephales promelas* (fathead minnow) - Mount, 1974[3] (60d - mortality, reproduction)	INERIS
Crustaceans & Other Invertebrates	inorganic mercury	0.25 - 6	Low: *Crepidula fornicata* (slipper limpet) - Thain, 1984 (112d - reproduction) High: *Penaeus indicus* (Indian prawn) - McClurgh, 1984 (28d - growth)	0.62 - 54	Low: *Hyalella azteca* (an amphipod) - Borgmann *et al*, 1993 (6-10 wk - reproduction) High: Geometric Mean - *Viviparis bengalensis* (snail) - Muley & Mane, 1988 (7d mortality)	Eurochlor
		0.1 - 70	Low: *Clavopsella michaeli* (a coelenterate) - Piraino, 1991 (8d) High: *Ophryotrocha diadema* (a marine worm) - Reish, 1978 and Reish & Carr, 1978 (geometric mean) (28d)	0.7	Geometric Mean - *Daphnia magna* (water flea); low [0.07] Enserink *et al.*, 1991 (21d)	INERIS
	methyl mercury	0.3	*Mytilus edulis* (blue mussel) - Pelletier, 1988 (32d - growth)	0.03 - 0.1	Low: *Dugesia dorotocephala* (turbellarian flatworm) - Best *et al.*, 1981 (14d - fissioning, neurotoxic effects) High: *Daphnia pulex* (water flea) - Tian-yi & McNaught, 1992 (30d - reproduction & growth)	Eurochlor
		0.3	*ditto*	0.09	*Daphnia pulex* (water flea) as above	INERIS

Table 6.2: Summary of NOECs for Aquatic Organisms

Group	Mercury Form	Marine Data NOEC µg/l		Freshwater Data NOEC µg/l		Source[1]
Aquatic Plants	inorganic mercury	0.9 - 330	Low: *Fucus serratus* (toothed wrack) - Strömgren, 1980 (10d - growth) High: *Dunaliella tertiolecta* (green algae) - Portmann, 1972 (18d - growth)	5 [TT] - 250	Low: *Microcystis aeruginosa* (blue-green algae) - Bringmann & Kühn, 1978 (8d TT - population, growth) High: *Anacystis nidulans* (blue-green algae) - Lee *et al*, 1992 (14d - growth)	Eurochlor
		0.9	*Fucus serratus* (toothed wrack) as above	2.5	*Microcystis aeruginosa* (blue-green algae) as above	INERIS
	methyl mercury	1	*Laminaria saccharina* (oarweed) - Thompson & Burrows, 1984 (14d - development of zoospores, growth of sporophytes)	1	based on saltwater data	Eurochlor
		no data		no data		INERIS
Protozoa	inorganic mercury	2.5	*Cristigera* sp. - Gray & Ventilla, 1973 (4-9 hr - reproduction)	16[TT]- 87	Low: *Chilomonas paramecium* (cryptomonad) - Bringman & Kühn, 1981 (48h TT - growth) High: Geometric Mean - *Tetrahymena pyriformis* (ciliate) based on Calabrese *et al*, 1973 (4h - mortality)	Eurochlor
		2.5	*ditto*	8	*Chilomonas paramecium* (cryptomonad) as above	INERIS
	methyl mercury	no data		14	*Tetrahymena pyriformis* (ciliate) - Thrasher *et al.*, 1972 (2-6 hr - growth)	Eurochlor
		no data		0.2	*Poterioochromonas malhamensis* (chrysophyte) - Röderer, 1983 (3d)	INERIS

Notes:

1) Eurochlor values are NOECs (unless otherwise indicated) as presented in Eurochlor (1999a): Risk Assessment for the Marine Environment - Mercury (Appendices 4a, 4b and 6). TT refers to 'toxicity threshold' which appears to be equivalent to 2 x NOEC (as interpreted by INERIS)

INERIS values are NOECs as presented in INERIS (2000): Compilation of Toxicological and Environmental Data on Chemicals – Mercury and its Derivatives

2) This value appears in the Eurochlor report but was rejected on grounds of validity as it was from a secondary source. However, the original source is validated by Sloof et al. (1995) and RIVM (1999)

Fish

In terms of fish, both Eurochlor (1999a) and INERIS (2000) provide geometric mean values for the fathead minnow *Pimephales promelas* of 0.68 µg/l and 0.3 µg/l inorganic mercury respectively. The lower of these values (INERIS, 2000) has been used since the geometric mean includes a reported result of 0.09 µg/l (from Snarski & Olson, 1982) which was not considered by Eurochlor to be of sufficient reliability to be included in their analysis.

As regards methyl mercury, Eurochlor (1999a) reports the most sensitive species as the brook trout *Salvelinus fontinalis* with a NOEC of 0.15 µg/l methyl mercury, having eliminated the lower NOEC value of 0.07 µg/l for the fathead minnow *Pimephales promelas* owing to secondary reporting and consequent low validity. INERIS (2000), however, validates this lower value and, as such a NOEC for fish of 0.07 µg/l methyl mercury has been used in the EUSES modelling.

Crustaceans and Other Invertebrates (including Daphnia)

The lowest NOEC value found for crustaceans and other invertebrates is 0.07 µg/l inorganic mercury for the water flea *Daphnia magna* reported in INERIS (2000). However, given the range of values reported for this species, INERIS (2000) provides a geometric mean value of 0.7 µg/l. This is higher than the 0.62 µg/l inorganic mercury value reported by Eurochlor (1999a) for *Hyalella azteca* (an amphipod). The values of 0.7 and 0.62 are used for *Daphnia* and 'other aquatic species' respectively (as shown in Table 6.1).

In terms of methyl mercury, the most sensitive species is the turbellarian flatworm *Dugesia dorotocephala* with a NOEC of 0.03 µg/l reported in Eurochlor (1999a). The most sensitive NOEC endpoint for the water flea *Daphnia pulex* of 0.09 µg/l is reported in both Eurochlor (1999a) and INERIS (2000). The values of 0.09 and 0.03 are used for *Daphnia* and 'other aquatic species' respectively (as shown in Table 6.1).

Aquatic Plants (including Algae)

Eurochlor (1999a) reports a threshold value of 5 µg/l for inorganic mercury for the most sensitive freshwater species, the blue-green alga *Microcystis aeruginosa*. Using the same original source material, INERIS (2000) reports a NOEC value of 2.5 µg/l.

As regards methyl mercury, there is no NOEC value in the literature for the freshwater environment and Eurochlor (1999a) uses the value of 1 µg/l methyl mercury found for the oarweed *Laminaria saccharina*. This value has been taken forward to EUSES modelling.

Protozoa

A range of NOECs for protozoa are reported in Eurochlor (1999a). The most sensitive freshwater result is a 'toxicity threshold' value of 16 µg/l for the cryptomonad *Chilomonas paramecium* which is reduced to 8 µg/l in the INERIS (2000) documentation using the same source data for inorganic mercury.

In terms of methyl mercury, Eurochlor (1999a) reports that the ciliate *Tetrahymena pyriformis* is the most sensitive species with a NOEC value of 14 µg/l. INERIS (2000) reports a lower NOEC value of 0.2 µg/l for the protozoan *Poterioochromonas malhamensis*.

PBT Assessment for the Marine Environment

As already indicated, marine environmental risk assessments are likely to be required when the revised TGD (currently in draft form) is formally adopted. These, in turn, are likely to require a PBT (persistence, bioaccumulation and toxicity) assessment which will involve two steps:

- identification of PBT substances using specific criteria; and
- an evaluation of the sources, major emissions and pathways to the marine environment to sufficiently establish the most appropriate and effective measures to reduce the releases to the marine environment.

Table 6.3 summarises the proposed PBT and vPvB (very persistent and very bioaccumulating) criteria that it is understood will be used in the first step.

Table 6.3: Proposed Criteria for Identification of PBT and vPvB Substances

Criterion	PBT Criteria	vPvB Criteria
P	Half-life > 60 d in marine water or > 40 d in freshwater[1] or half-life > 180 d in marine sediment or > 120 d in freshwater sediment[1]	Half-life > 60 d in marine or freshwater or >180 d in marine or freshwater sediment
B	BCF > 2,000	BCF > 5,000
T	Chronic NOEC < 0.01 mg/L or CMR (carcinogenic, mutagenic or toxic for reproduction) or endocrine disrupting effects	Not applicable

Notes:

1) For the purpose of marine environmental risk assessment, half-life data in freshwater and freshwater sediment can be overruled by data obtained under marine conditions.

It is intended that, generally, such criteria will be applied to organic compounds. Since metals (including mercury and its compounds) do not 'biodegrade' in the usual sense of the word, they would all be classified as (very) persistent (however defined). As noted in Section 5.5.3, BCF factors of 5,000 and 50,000 have been used in this analysis for inorganic and organic mercury respectively. As such, mercury and its compounds would be expected to meet the proposed 'very bioaccumulating' criterion. For completeness, it can be seen from Table 6.3, that the (PBT) toxicity criteria would be met for both inorganic and organic compounds.

The conclusion that mercury and its compounds are likely to be classified, at least, as PBT substances is not surprising and is, of course, one of the key drivers for the activities of OSPAR and other bodies to limit mercury discharges to the marine environment and for the designation of mercury and its compounds as priority hazardous substances under the Water Framework Directive.

6.2.4 Terrestrial Compartment - Soil

Within the terrestrial compartment, the focus of interest is on the effects of inorganic mercury since methylation appears to be mainly limited to the aquatic environment. However, historically, organomercurials have been used as anti fungal agents for seeds and plants - although this use has been banned for some time within the EU. As a result, the presence of organic mercury in the terrestrial compartment is likely to be associated with contamination (UNEP, 2002). Interestingly, work is under way to develop genetically-modified crops which can be planted in contaminated areas (not necessarily within the EU) to break down the organic mercury into the less harmful inorganic mercury (as discussed in Petra & Sharma, 2000).

On this basis, the analysis has been restricted to inorganic mercury and, ideally, the TGD and *EUSES* software model require data on NOECs for plants, earthworms, micro-organisms and other terrestrial species. Table 6.4 summarises the NOEC values used with further detail provided below.

Table 6.4: Terrestrial Data used in EUSES Modelling

Inorganic Mercury	NOEC mg/kg dw	Source Document
NOEC Plants	0.125	*Pennisetum thypoideum* (cereal) - Mhatre *et al*, 1984 (quoted in Eurochlor, 1999)
NOEC Earthworms	<0.5	*Octochaetus pattoni* (earthworm) - various sources quoted in Eurochlor, 1999.
NOEC Micro-organisms	1.4	Microorganisms ATP - Zelles *et al.*, 1985 (quoted in INERIS, 2000)
NOEC Other terrestrial species (excluding birds & mammals)	0.121	*Eyrepocnemis plorans* (grasshopper) - Devkota & Schmidt, 1999 (quoted in USEPA *ECOTOX* data-base)

Plants

Data on NOECs for plants from three studies are presented by Eurochlor (1999) for inorganic mercury. No data are presented by INERIS (2000). Searches of the USEPA's *ECOTOX* data-base and a more general search of the *Web of Science* abstract data-base produced some further information. Petra & Sharma (2000) review the results of numerous studies on the impacts of mercury (both inorganic and organic) upon plants. As would be expected, there is a consensus that organic mercury is more toxic to plants than inorganic mercury.

For inorganic mercury (mercuric chloride), the lowest NOEC found was that of 0.125 mg/kg dw presented in Eurochlor (1999) based on the effects on leaf area and leaf injury of short-term (24 hr) exposure to mercuric concentrations in the range 1 - 1,000 µg/l. It is considered that this value may err on the side of pessimism as it is noticeably lower than the values reported elsewhere (and, indeed, was assigned a 'validity score' of 3 by Eurochlor to indicate a low level of reliability).

Earthworms

Limited data on NOECs for earthworms are presented by Eurochlor (1999) and INERIS (2000). As for plants, searches of *ECOTOX* and the *Web of Science* were undertaken but produced limited information.

For inorganic mercury (mercuric chloride), the lowest value found was that of 0.5 mg/kg dw presented in Eurochlor (1999) for *Octochaetus pattoni* based on a 60d LCLo (lowest lethal concentration) for inhibition of reproduction (and an LC50 of 0.75 mg/kg dw). Clearly, the NOEC value will be lower.

Of note is that for organic mercury (methyl mercury chloride), the only NOEC found was that of 3.7 mg/kg dw presented in INERIS (2000) for the 'standard' manure worm (*Eisenia foetida*) based on an 84d test. This value can be compared with the corresponding inorganic NOEC of 100 mg/kg dw[47].

Micro-organisms

Limited data on NOECs for micro-organisms are presented by INERIS (2000), although not by Eurochlor (1999). As before, searches of *ECOTOX* and the *Web of Science* were undertaken but produced no significant findings.

For inorganic mercury (mercuric chloride), the lowest NOEC found was that of 1.4 mg/kg dw presented in INERIS (2000) for effects on levels of ATP (adenosine triphosphate) based on a 48d test.

NOEC for other terrestrial species

Limited data on NOECs for other species are presented by Eurochlor (1999) for inorganic mercury. No data are presented by INERIS (2000). As before, searches of *ECOTOX* and the *Web of Science* were undertaken.

For inorganic mercury (mercuric chloride), the lowest NOEC found[48] was that of 0.121 mg/kg dw for development effects on *Eyrepocnemis plorans* (grasshopper). The same result was also obtained for another grasshopper species, *Aiolopus thalassinus*.

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47 Fischer E & Koszorus L (1992): *Sublethal Effects, Accumulation Capacities and Elimination Rates of As, Hg and Se in the Manure Worm, Eisenia Fetida (Oligochaeta, Lumbricidae)*, Pedobiologia, Vol 36 pp 172-178 (as reported on the USEPA *ECOTOX* data-base).

48 Devkota B & Schmidt GH (1999): *Effects of Heavy Metals (Hg^{2+}, Cd^{2+}, Pb^{2+}) during the Embryonic Development of Acridid Grasshoppers (Insecta, Caelifera)*, Archives of Environmental Contamination and Toxicology, Vol 36 pp 405-414 (as reported on the USEPA *ECOTOX* data-base).

6.2.5 Terrestrial Compartment - Birds

The TGD and *EUSES* software model require data on NOECs for birds. NOEC values were derived for inorganic mercury (typically mercuric chloride) and organic mercury (typically methyl mercury chloride). Table 6.5 summarises the NOEC values used with further detail provided below.

Table 6.5: Bird Data used in EUSES Modelling

Inorganic Mercury	**NOEC**	**Source Document**
NOEC (Feed)	1.1 mg/kg feed	Starlings - Nicholson *et al*., 1984 (quoted in Eurochlor, 1999 and INERIS, 2000)
Methyl Mercury		
NOEC (Feed)	0.36 mg/kg feed	Pheasants (& chickens) - Gardiner, 1972 (quoted in INERIS, 2000)

For inorganic mercury (mercuric chloride), the lowest NOEC found was that of 1.1 mg/kg feed presented in Eurochlor (1999) and in INERIS (2000) for starlings based on a 56d test.

For organic mercury (methyl mercury chloride), the lowest NOEC found was that of 0.36 mg/kg feed presented in INERIS (2000) for pheasants and chickens based on a 20d test.

6.2.6 Terrestrial Compartment - Mammals

The *EUSES* software model requires data on NOAELs (no observed adverse effect level) for oral, dermal and inhalation routes for mammals. NOAEL values have been derived for inorganic mercury (typically mercuric chloride but also including elemental mercury vapour) and organic mercury (typically methyl mercury chloride).

ATSDR (1999) presents an authoritative overview of the toxic effects of mercury and its compounds on mammals and humans and has been used as the source document for the values used in *EUSES*. Comparisons were also made with data presented in Eurochlor (1999) and INERIS (2000).

Table 6.6 summarises the NOAEL values used with further detail provided below.

Table 6.6: Mammal Data used in EUSES Modelling

Inorganic Mercury	**NOAEL**	**Source Document**
Oral	0.23 mg/kg/day	Rat - Dieter *et al*., 1992 & NTP, 1993 (quoted in ATSDR, 1999)
Dermal	0.23 mg/kg/day	Taken to be the same as for oral route (EUSES default)
Inhalation	0.075 mg/m^3	Warfvinge *et al*., 1995 (quoted in ATSDR, 1999)
Organic Mercury		
Oral	0.011 mg/kg/day	Monkey - by Kawaski *et al*., 1986 (quoted in INERIS, 2000)
Dermal	0.011 mg/kg/day	Taken to be the same as for oral route (EUSES default)
Inhalation	0.0075 mg/m^3	Taken to be 10% of corresponding value for inorganic mercury

Oral Route

For inorganic mercury, the lowest NOAEL was found to be 0.23 mg/kg/day (as reported in ATSDR, 1999) for renal effects after a 26 wk test.

For organic mercury, the lowest 'systemic' NOAEL reported in ATSDR (1999) is 0.02 mg/kg/day (based on renal effects for a 2 year rat study undertaken by Verschuuren *et al*., 1976). The same value is derived for neurological effects (based on the 'hopping reaction' of cats after a 2 year study undertaken by Charbonneau *et al.*, 1976). Reference is also made to Bornhausen *et al.*, 1980 in which the NOAEL for developmental effects (performance in offspring) after 4 days exposure was determined to be 0.004 mg/kg/day. However, ATSDR (1999) notes that this finding has yet to be confirmed by other studies.

INERIS (2000) reports a NOEC of 0.22 mg/kg feed (based on a 1 year monkey study undertaken by Kawaski *et al*., 1986). Using the NOEC (feed) to NOAEL (oral) conversion (for monkeys) provided by *EUSES* gives a NOAEL of 0.011 mg/kg/day and it is this value which will be taken forward in the analysis.

Dermal Route

No data on the effects of dermal exposure are reported by ATSDR (1999) nor by Eurochlor (1999) and INERIS (2000). For this route, the NOAEL has been assumed to be the same as for the oral route (which is the *EUSES* default).

Inhalation Route

Data on inhalation toxicity generally relates to exposure of elemental mercury vapour. ATSDR (1999) reports an inhalatory NOAEL of 0.1 mg/m^3 (for renal effects based on an 18 month study of various mammals undertaken by Ashe *et al.*, 1953). For immunological/lymphoreticular effects, ATSDR (1999) reports a slightly lower value of 0.075 mg/m^3 (based on a 10 wk study on mice undertaken by Warfvinge *et al.*, 1995) and this value will be taken forward in the analysis for inorganic mercury.

No data have been located for the effects on animals of inhalation of organic mercury vapours. In the absence of such data, the NOAEL value has been assumed to be 10% of that for inorganic mercury derived above.

6.3 Human Toxicity

6.3.1 Overview

Limited data are presented on human toxicity in WS Atkins (1998). There is a wealth of information on human toxicity of mercury and mercury compounds and much of it has been reviewed in a comprehensive US report (ATSDR, 1999). Furthermore, an authoritative review of mercury toxicity has been recently published by the World Health Organisation (WHO, 2000). A further review of these and other key documents has also been published recently by the UK Government (DEFRA, 2002).

Recent reviews which concentrate on the assessment of health effects of exposure to methyl mercury include NIEHS (1999), National Research Council (2000) and US EPA (2001). In broad terms, methylated mercury is more toxic than inorganic mercury salts, which, in turn, are more toxic than elemental mercury. Interestingly, the ingestion of elemental mercury (from, say, thermometers) is very unlikely to result in adverse effects due to the very low absorption by the intestine (less than 0.01%)

The prime effects of exposure to mercury and its compounds are:

- *for mercury vapour (via inhalation),* effects on the nervous system (for example, tremors and memory loss) although these are often reversible;
- *for inorganic mercury compounds (via ingestion),* the kidney is the target organ; and
- *for organic mercury compounds (via ingestion),* the damage is mainly to the central nervous system and the effects are irreversible. Such effects have been observed in children whose mothers were exposed to methyl mercury when pregnant.

Mercury and its compounds are not considered to be carcinogenic.

The *EUSES* software model requires data on NOAELs (no observed adverse effect level) for oral, dermal and inhalation routes for humans. NOAEL values have been derived for inorganic mercury (typically mercuric chloride but also including elemental mercury vapour) and organic mercury (typically methyl mercury chloride). Table 6.7 summarises the NOAEL values used with further detail provided below.

Table 6.7: Human Data used in EUSES Modelling

Inorganic Mercury	**NOAEL**	**Source Document**
Oral	2 µg/kg/day	ATSDR (1999)
Dermal	2 µg/kg/day	Taken to be the same as for oral route (EUSES default)
Inhalation	0.2 µg/m^3	ATSDR (1999)
Organic Mercury		
Oral	0.1 µg/kg/day	USEPA (2001)
Dermal	0.1 µg/kg/day	Taken to be the same as for oral route (EUSES default)
Inhalation	0.02 µg/m^3	Taken to be 10% of corresponding value for inorganic mercury

6.3.2 Inhalation

About 80% of inhaled mercury vapour is absorbed via the lungs and retained by the body. The absorption rate for inorganic mercury is about half of this value (although it does depend on other factors - such as associated particle sizes). As already mentioned (see Section 4.5.3), systemic effects have been observed after long-term (occupational) exposure to levels of the order of 0.1 mg/m^3. Some studies have observed other effects, notably neurological, at lower concentrations (ATSDR, 1999) - down to 0.026 mg/m^3. On this basis and after various adjustments and safety factors, the US has set an MRL (minimal risk level) for long term exposure to mercury vapour as 0.2 $\mu g /m^3$.

Although WHO (2000) reports some (human) effects at lower workplace exposure levels - down to 0.01 mg/m^3 - WHO has recommended a 'safe' guideline of 1 $\mu g/m^3$. These various calculations are illustrated in Box 6.1.

Box 6.1: Deriving a 'Safe' Level from Occupational LOAELs

1) WHO (2000):	**LOAEL (workers):**	**20 $\mu g/m^3$**
	Increase by a factor of three to correct for 'true' exposure:	60 $\mu g/m^3$
	Reduce by a factor of three to adjust for longer 'public' exposure:	20$\mu g/m^3$
	Divide by 10 to account for variations in population sensitivity	2 $\mu g/m^3$
	Divide by 2 for LOAEL uncertainty:	**1 $\mu g/m^3$**
2) ATSDR (1999):	**LOAEL (workers):**	**26$\mu g/m^3$**
	Reduce by a factor of 168/40 to adjust for longer 'public' exposure (40 hours worker exposure vs 168 (24 x 7) hours public exposure):	6.2 $\mu g/m^3$
	Divide by 10 to account for variations in population sensitivity	0.6 $\mu g/m^3$
	Divide by 3 for LOAEL uncertainty:	**0.2 $\mu g/m^3$**

Several studies during recent decades demonstrated that mercury vapours are released from dental amalgam filling into the oral cavity. The estimate for the rate of release in people with amalgam fillings is 3 - 17 µg Hg/day (WHO, 1990). The concentration of mercury vapour in the oral cavity can reach occupational health danger levels, but the quantity of vapour is small because the volume of the cavity is small (Clarkson, 2002). Two well conducted epidemiological studies demonstrated that dental amalgam did not affect mental health (Bjorkman *et al.*, 1996; and Saxe *et al.*, 1995).

The value taken forward in the analysis is a NOAEL value of 0.2 $\mu g/m^3$ for inhalation for inorganic mercury. No data have been located for the inhalation of organic mercury and a value of 0.02 $\mu g/m^3$ is assumed.

6.3.3 Dermal Exposure

Dermal exposure is not generally considered to be a significant route when considering the toxicity of mercury and its compounds. However, ATSDR (1999) reports a case in which the accidental spillage of a few drops of dimethyl mercury on the latex gloves of a chemistry professor led to death within several months (via both

dermal exposure - as the gloves were readily penetrated by the dimethyl mercury - and inhalation).

The NOAEL values taken forward in the analysis are assumed to be the same as those derived for the oral route (which is also the *EUSES* default).

6.3.4 Ingestion

Overview

As already noted, absorption of elemental mercury in the intestine is very low while that for inorganic mercury compounds is of the order of 10-15%. By contrast, there is almost complete absorption of methylated mercury compounds (WHO, 2000).

The greatest amount of work undertaken on mercury toxicity is in relation to ingestion of mercury contaminated foodstuffs. This has been spurred by various tragedies including Minamata and Niigata in Japan in which industrial discharges of methyl mercury and other mercury compounds (during the late 1950s and early 1960s) led to elevated levels of methyl mercury in fish. By 1971, 269 cases of Minamata disease[49] had been reported of which 55 proved fatal and by 1989, there were 2217 confirmed cases in Minamata and 911 in Niigata. In Iraq in 1971-72, ingestion of bread made with cereals treated with organic mercury fungicides led to 6,000 hospital admissions and 500 deaths (WHO, 1996).

Inorganic Mercury

Many of the ingestion toxicity tests relate to mercuric chloride which has been found to be more toxic than the natural ore mercuric sulphide. Inspection of the results presented in ATSDR (1999) suggests that the effects are dependent on the ingestion rate (mg/kg bw/day[50]) rather than on the dose (ingestion rate x time). The most susceptible part of the body appears to be the kidneys with reported NOAELs of 0.93 and 0.23 mg/kg/day for acute and intermediate exposures respectively. On this basis and after various adjustments and safety factors, the US has set MRLs for acute and intermediate ingestion exposures (to inorganic mercury) as 7 and 2 µg/kg/day respectively. The latter value has been taken forward as the NOAEL value for the oral route for inorganic mercury.

Organic Mercury

In relation to organic mercury, the greatest public health concern relates to methyl mercury exposure from ingestion of contaminated food, particularly the edible tissue of fish. All exposure intake values estimated for methyl mercury are presented in Table 6.8.

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49 The symptoms of Minimata disease are those of methyl mercury poisoning and include uncoordinated movements, abnormal reflexes, speech problems and seizures.

50 mg/kgbw/day refers to mg ingested per kg of bodyweight per day (and is usually shortened to mg/kg/day).

Table 6.8: Exposure Estimates for Methyl mercury and Percentage (%) of Total Exposure Based on Adults in the General Population

Exposure Source	Exposure Estimate (mg/kg/day)	Percent of Total Exposure	Percent of RfD[1]
Ambient water intake	4.3×10^{-9}	0.005%	0.004%
Drinking water intake[2]	5.6×10^{-8}	0.061%	0.056%
Nonfish dietary intake	0	0%	0%
Freshwater/estuarine fish intake	6.5×10^{-5}	70.6%	65.0%
Marine fish intake	2.7×10^{-5}	29.3%	27.0%
Air intake	4.6×10^{-9}	0.005%	0.005%
Soil Intake	1.3×10^{-9}	0.001%	0.001%
Total intake	**9.2×10^{-5}**	**100%**	**92.1%**

Source: US EPA (2001)

Notes:

1) The USEPA's 'reference dose' (RfD) is set at 0.1 µg/kg/day (i.e. 1×10^{-4} mg/kg/day).

2) This represents the high end of the range of estimates. Because the contribution of ambient water or drinking water intake to total exposure is so negligible in comparison to the sum of intake from other sources, there is no difference in the total exposure estimated using either of these two alternatives.

The major toxic effects of methyl mercury are on the central nervous system. The mechanisms and outcomes of toxic effects on the developing brain differ from those on the mature organ.

In adults, paresthesia (prickling sensation) is the first symptom to appear at the lowest dose. This may progress to cerebellar ataxia (clumsiness or unsteadiness), dysarthria (speech disorder), constriction of the visual fields and loss of hearing. These signs and symptoms are caused by the loss of neuronal cells in specific anatomical regions of the brain (Clarkson, 2002). Although, most epidemiological studies and clinical reports on adults demonstrated signs and symptoms of toxic effects of methyl mercury associated mainly with the central nervous system, recent reports indicate the possibility that methyl mercury may have adverse effects on the cardiovascular system (Salonen *et al.*, 1995; Salonen *et al*., 2000).

A number of epidemiological studies involving new-borns and children from mothers exposed to methyl mercury indicated higher susceptibility of the developing brain, compared to the mature organ. The first such indications come from the studies of Minamata and Iraq outbreaks of methyl mercury poisonings. It was possible to construct a dose-response relationship between peak hair mercury levels in pregnancy versus number of abnormal offspring showing developmental delays and abnormal neurological findings (Marsh *et al*., 1987; Cox *et al*., 1989). There are no data to indicate that methyl mercury is carcinogenic in humans.

The quantitative health risk assessment for non-carcinogenic chemicals is based on the reference dose (RfD). This is an estimate of a daily exposure of the human population, including sensitive subgroups, that is likely to be without an appreciable risk of deleterious health effects during a lifetime. The earlier RfD of 0.1 µg/kg/day

was established in 1995 by the US EPA as the Agency's consensus estimate. Marsh *et al.* (1987) was chosen as the most appropriate study at that time for determination of an RfD to protect infants born to mothers exposed to methyl mercury during pregnancy.

Since that time, considerable new data on the health effects of methyl mercury have appeared in the literature. Neurotoxicity, particularly in developing organisms, has been observed as the adverse effect at the lowest dose of methyl mercury. The National Research Council (NRC) of the National Academy of Sciences in the USA and US EPA considered three epidemiological studies most suitable for quantitative risk assessment: the Seychelles Child Development Study (Davidson *et al*., 1998 & 2001); studies of Children in the Faroe Islands (Grandjean *et al*., 1997; Murata *et al*., 1999); and the study of Children in New Zealand (Mitchell *et al*., 1982). All cohorts consisted of children exposed *in utero* through maternal consumption of contaminated marine food. In both the Faroe Islands and the New Zealand studies, neurodevelopmental toxic effects of methyl mercury were found to be dose-related. These effects include developmental deficits in memory, attention and language. No evidence of impairment associated with exposure was found in the Seychelles study.

In 1999, ATSDR published a revised Minimal Risk Level for methyl mercury of 0.3 µg/kg/day, based on a dose of 1.3 µg/kg/day derived from the Seychelles study data, which does not necessarily reflect the NOAEL.

The Committee on Toxicological Effects of Methylmercury, established in 1999 by the US National Research Council, reviewed and evaluated scientific data on health effects of methyl mercury. In its published report, NRC (2000) concluded that differences in the study designs and in the characteristics of the study populations might explain the differences in findings between the Faroe and Seychelles studies.

Taking into account that a large body of scientific evidence showing adverse developmental neurotoxic effects was available from well-designed epidemiological studies, the Committee concluded that a RfD should not be derived from a study such as the Seychelles study which did not observe any associations with exposure to methyl mercury. Given the strength of the Faroe Islands study, the Committee concluded that it would be most appropriate if a RfD was derived from this critical study.

US EPA followed the recommendations of the NRC in the subsequent development of a RfD. The critical endpoint was drawn from the series of neuropsychological test results from the Faroese cohort. The RfD derived in this assessment is 0.1 µg/kg bw/day. In the published document (US EPA, 2001), the authors emphasise that there are currently no data that would support the derivation of a RfD applicable to children specifically. The derived RfD is applicable to lifetime daily exposure for all populations including sensitive subgroups - with particular reference to preventing the occurrence of developmental effects amongst children whose mothers are exposed to methyl mercury during pregnancy.

7. RISK CHARACTERISATION

7.1 Overview

The purpose of the risk characterisation is to assess whether the predicted concentrations in the environment exceed those concentrations which produce adverse effects in either the environment or in humans. The TGD procedure (as incorporated into *EUSES*) involves:

- selecting the lowest NOEC for the area of interest (based on the toxicity data presented in Section 6);
- dividing the lowest NOEC by an assessment (or safety) factor to derive the PNEC (predicted no-effect concentration);
- selecting the appropriate PEC (based on the results of the *EUSES* analysis presented in Section 5); and
- dividing the PEC by the PNEC to give an indication of the level of the associated risk.

Where there are several relevant NOECs (as in this case), the TGD (and *EUSES*) recommends an assessment factor of 10. However, in the case of metals, it is anticipated that a lower factor will be incorporated into the revised TGD. At an expert workshop[51], it was agreed that a value between 1 (exceptionally) and 5 would be more appropriate. For this analysis, an assessment factor of 5 will be used to err on the side of caution and to reflect some of the uncertainties in both the analysis and the derivation of NOECs.

7.2 Risks to the Environment

7.2.1 Aquatic Environment

The lowest NOECs derived for the aquatic environment were 0.3 and 0.03 µg/l for inorganic and organic mercury respectively (see Table 6.1). Applying an assessment factor of 5 gives PNECs of 0.06 µg/l (60 ng/l) and 6 ng/l respectively. Since measured concentrations (for inorganic mercury) are typically in the range 1 - 10 ng/l (see Table 4.1), it can be seen that only PECs which are far in excess of existing concentrations will to lead to PEC/PNEC ratios of greater than one.

The resultant PEC/PNEC ratios for the PECs associated with mercury production, product manufacture and product use are presented in Table 7.1. Since the 'local' PEC values are very similar to the regional PEC value (see Table 5.10), the regional and local PEC/PNEC ratios are very similar.

[51] Report of the Expert Consultation Workshop on Statistical Extrapolation Techniques for Environmental Effects Assessment held in London, 17/18 January 2001 to discuss aspects of the revised TGD.

Table 7.1: PEC/PNEC Ratios for the Aquatic Environment (Water) for Mercury & Products		
Parameter	**Mercury Species**	
	Inorganic	**Organic**
Regional PEC/PNEC associated with manufacture and use of mercury in products under study	0.011	0.011
Local PEC/PNEC ratios associated with mercury production:		
Primary production (Spain)	0.011	0.011
Production from non-ferrous by-products		
Secondary production		
Local PEC/PNEC ratios associated with product manufacture:		
Dental amalgam	0.011	0.011
Batteries	0.012	0.012
Lamps	0.011	0.011
Measuring equipment	0.011	0.011
Electrical equipment	0.011	0.011

EUSES also derives a PNEC for sediments (based on the PNEC for water), which for inorganic mercury was estimated to be 7.56 mg/kg dw and for organic mercury, a PNEC of 21.3 µg/kg dw was derived[52]. The associated PEC/PNEC ratios are presented in Table 7.2.

Table 7.2: PEC/PNEC Ratios for the Aquatic Environment (Sediment) for Mercury & Products		
Parameter	**Mercury Species**	
	Inorganic	**Organic**
Regional PEC/PNEC associated with manufacture and use of mercury in products under study	0.011	0.38
Local PEC/PNEC ratios associated with mercury production:		
Primary production (Spain)	0.006	0.22
Production from non-ferrous by-products		
Secondary production		
Local PEC/PNEC ratios associated with product manufacture:		
Dental amalgam	0.006	0.22
Batteries		
Lamps		
Measuring equipment		
Electrical equipment		

[52] The calculation of the PNEC in sediment (TGD Eqn. 54) depends directly on the solid-water partition coefficient in sediment - i.e. the resultant PNEC varies with the value used. Whilst Eurochlor (1999) and INERIS (2000) use the same value (126,000 l/kg) derived for inorganic mercury, Sunderland & Gobas (2001) suggest a much lower value of 100 l/kg. In this analysis, a geometric mean of 3,550 was used.

It may be noted that as local PEC values were not generated by *EUSES* (see Table 5.11), it was necessary to have a 'shadow' *EUSES* run based on methyl mercury chloride and then to scale the 'local' results against the pre-derived 'regional' values (i.e. 10% of the inorganic values as presented in Table 5.11).

As can be seen from Tables 7.1 and 7.2, the PEC/PNEC ratios are generally well below unity in all cases. The exceptions are the results for organic mercury in sediments where relatively higher results were obtained due, in part, to the choice of partition coefficient.

7.2.2 Terrestrial Compartment

The lowest NOEC derived for the terrestrial environment was 0.121 mg/kg dw for inorganic mercury (see Table 6.4). Applying (as for the aquatic compartment) an assessment factor of 5 gives a PNEC of 24 µg/kg dw. Since existing concentrations are typically in the range 50 - 100 µg/kg dw (see Table 4.1), it can be seen that PECs which contribute significantly to the existing concentrations may lead to PEC/PNEC ratios of greater than one.

The associated PEC/PNEC ratios are presented in Table 7.3.

Table 7.3: PEC/PNEC Ratios for the Terrestrial Environment for Mercury & Products

Parameter	**Mercury Species: Inorganic**
Regional PEC/PNEC associated with manufacture and use of mercury in products under study	0.18
Local PEC/PNEC ratios associated with mercury production:	
Primary production (Spain)	0.25
Production from non-ferrous by-products	0.19
Secondary production	0.19
Local PEC/PNEC ratios associated with product manufacture:	
Dental amalgam	0.19
Batteries	0.19
Lamps	0.20
Measuring equipment	0.19
Electrical equipment	0.19

As can be seen from Table 7.3, the PEC/PNEC ratios are below unity in all cases.

7.2.3 Secondary Poisoning

EUSES considers two routes to secondary poisoning of birds or mammals:

- water to fish to fish-eating birds or mammals; and
- soil to earthworm to worm-eating birds or mammals.

These food chains are associated with organic mercury in the aquatic environment and with inorganic mercury in the terrestrial environment. PNECs are derived from NOEC data presented in Section 6 on birds (Table 6.5) and mammals (Table 6.6) as well as accounting for the bio-concentration factors. These values are then compared to the water and soil PECs at a 'local' level and the results are summarised in Table 7.4.

Table 7.4: PEC/PNEC Ratios for Local Secondary Poisoning for Mercury & Products

Scenario	Aquatic Food Chain (Organic Mercury)	Terrestrial Food Chain (Inorganic Mercury)
Local PEC/PNEC ratios associated with mercury production:		
Primary production (Spain)	0.92	<0.001
Production from non-ferrous by-products		
Secondary production		
Local PEC/PNEC ratios associated with product manufacture:		
Dental amalgam	0.92	<0.001
Batteries	0.93	
Lamps		
Measuring equipment		
Electrical equipment		

As can be seen from Table 7.4, PEC/PNEC ratios are predicted to approach unity for the aquatic food chain due not only to the low PNECs for organic mercury but also to the high bio-concentration factor used (50,000). By contrast, there is a negligible risk of secondary poisoning via the terrestrial food chain. The results of the risks to the environment are discussed further in Section 7.4.

7.3 Risks to Humans

7.3.1 Direct Risks

No attempt has been made to quantify risks in the workplace due to the high level of awareness of mercury risks and the (generally) strict measures which have been taken to reduce worker exposures.

7.3.2 Man Exposed via the Environment

The 'margins of safety' (MOS) for man exposed via environmental routes are shown in Table 7.5 using the 'reference doses' of 2 and 0.1 µg/kg bw/day for inorganic (including elemental) and organic mercury respectively (see Table 6.7). The MOS values are simply the ratios of the reference dose to the human intake of the substance via the environment (including inhalation, dietary intake, etc.) for each scenario.

EUSES calculates the MOS for both inhalation (MOS-air) and total environmental exposure (MOS-total) and both are presented in Table 7.5. For mercury, the MOS-air values will tend to be associated with elemental mercury whilst the MOS-total values will tend to be associated with dietary intake of inorganic and organic mercury.

As can be seen from Table 7.5, the MOS values exceed unity in all cases.

Table 7.5: Margin of Safety (MOS) Values for Human Exposure via the Environment for Mercury & Products at Regional and Local Levels

Parameter	MOS-Air (Mercury)	MOS-Total (Inorganic)	MOS-Total (Organic)
Regional MOS values associated with manufacture and use of mercury in products under study	>100	>100	18
Local MOS values associated with mercury production:			
Primary production (Spain)	6.5	>100	18
Production from non-ferrous by-products	>100		
Secondary production	>100		
Local MOS values associated with product manufacture:			
Dental amalgam	>100	>100	18
Batteries	>100		
Lamps	55		
Measuring equipment	>100		
Electrical equipment	>100		

7.4 Discussion

As detailed in the Technical Guidance Document (TGD), there are three broad conclusions that can be drawn from an environmental risk assessment of an existing substance.

- *Conclusion (i)* there is a need for further information and/or testing;
- *Conclusion (ii)* there is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already; or
- *Conclusion (iii)* there is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

As stated in the TGD, where the PEC/PNEC ratio is found to be less than or equal to one for each compartment, Conclusion (ii) shall apply. As can be seen from Tables 7.1 to 7.4, this condition is met for the use of mercury in the products under study - although the PEC/PNEC ratio approaches unity in relation to secondary poisoning via the aquatic food chain. In other words, further risk reduction measures (over and beyond those already planned) would not be required on the basis of the risk assessment alone.

However, it is recognised that there is widespread concern over the presence of mercury in the environment and a desire to further limit the potential impacts of mercury usage. Although it would appear that the broad objective of the Aarhus Convention (see Section 1.2) to reduce mercury emissions to below 1990 levels has been met (since most uses show a significant decline during the 1990s), the Convention requires further precautionary measures to be considered. Similarly, HELCOM and OSPAR have an interest in reducing mercury emissions to the marine environment.

Under the revised TGD, which is in preparation, there is little doubt that mercury and its compounds will be designated PBT (persistent, bioaccumulative and toxic) substances in respect of the marine environment. Such factors led to the designation of mercury and its compounds as priority hazardous substances under the Water Framework Directive which will necessitate consideration to be given to further reductions in usage and emissions.

In relation to human toxicity, the assessment of human exposure via the environment suggests that there is a considerable margin of safety (i.e. MOS >1) associated with the products under study as shown in Table 7.5. However, the developmental toxicity effects of methyl mercury may result in further pressures to limit the use and emissions of mercury and its compounds.

Of the estimated 160 t/year of mercury emitted to the environment from anthropogenic sources in the EU and the three accession countries (EC, 2001b), the products under study account for less than 25 t/year. There may, however, be areas where further reductions could be achieved in usage and/or associated emissions across the range of products examined here. Such reductions should be proportional to the relative emissions within the context of the overall anthropogenic use of mercury and the associated emissions.

In relation to the products under study, dental amalgam is the largest use with over 10 t/year of mercury being emitted to the environment. The dominant source of emissions is releases from crematoria and this may be an area for further investigation. Measuring and control equipment would also appear to be a key source with emissions of 8.5 t/year - primarily to the atmosphere from landfills. Within this sector, there may be areas where usage and/or emissions could be reduced. The other three products areas (batteries, lighting and electrical equipment) have significantly lower usage and associated emissions.

More generally, it is worth noting that the production of skin lightening creams involves the consumption of mercury in greater quantities than those used for measuring and control equipment - although as discussed in Section 3.7, this may be an area where more enforcement rather than more controls is required.

Finally, it is important to stress that any proposed controls would need a further investigation of the advantages and drawbacks under the requirements of the Marketing and Use Directive (76/769/EEC).

8. OVERALL FINDINGS

8.1 Mercury Use in Products under Study

It has been possible to characterise the use of mercury in the main product groups which are the subject of this study - dental amalgam, batteries, discharge lamps, measuring (and control) equipment and electrical control and switching equipment. Although research and consultation has enabled aspects of the various lifecycles to be quantified, comprehensive data were not obtained for all areas with particular reference to the last two product groups (measuring (and control) equipment and electrical control and switching).

The mercury used in the products within the EU (and the three accession countries) comes: from primary production (in Spain); as a by-product of non-ferrous metal production; from a mercury recycling plant; or as an import (usually within the product, as in the case of thermometers). Some data on these production routes (and associated emissions) were obtained but determining the precise scale and extent of the mercury 'business' proved difficult. However, it would appear that the recovery of mercury from decommissioned chlor-alkali facilities is rapidly become the major source of mercury within the EU.

Overall, there is clear evidence that the use of mercury in batteries and lamps has significantly reduced in recent years. There has also been a decline in the use of dental amalgam and, as importantly, there has been a significant increase in the use of mercury recovery devices (separators) in dental surgeries. Although there has been a reduction in the use of mercury thermometers and sphygmomanometers (for measuring blood pressure), it has been difficult to estimate the overall use of mercury within this sector. Similarly, whilst there has been a move away from the extensive use of mercury tilt switches in domestic products (including cars, white goods, etc.), the extent of mercury use in other applications within this sector has been difficult to determine.

For each product group, it was possible to develop a flowchart for the lifecycle and associated emissions (based on an approach adopted by the Swedish authorities).

It is estimated that the current usage of mercury in these product groups is about 120 tonnes per year (60% of which is associated with dental amalgam) in the EU with, perhaps, a further 50 tonnes per year used in the three accession countries under study (Czech Republic, Poland and Slovenia). It is estimated that the emissions to the environment associated with the production of mercury used in these products, product manufacture and product use is less than 25 tonnes per year.

8.2 Mercury Use in Other Products

Mercury is used in numerous diverse products and applications, ranging from its use in lighthouses (some lights revolve in a bath of mercury) to recoil suppression systems in rifles. However, these account for a relatively low consumption with one

notable exception. It would appear that, perhaps, 50 tonnes per year of mercury is used in the manufacture (within the EU) of skin lightening creams and other cosmetic products, most of which are exported to, and consumed in, Africa. It should be noted that the marketing of mercury containing cosmetic products (with the exception of trace amounts in eye products) is not permitted within the EU.

8.3 Other Sources of Mercury

Large quantities (thousands of tonnes) of mercury are used in chlor-alkali plants throughout the world. Most EU countries have such plants (as does the Czech Republic and Poland) and current estimates of mercury consumption (within the EU) are of the order of 150 tonnes per year. As indicated above, the planned phase-out of mercury usage in chlor-alkali plants will lead to a substantial flow of recovered mercury onto the market over the next 20 years (perhaps 650 tonnes per year within Europe). The associated emissions (primarily to atmosphere) are estimated to be less than 10 tonnes per year although significant amounts of mercury are unaccounted for.

Although mercury is a trace constituent of fossil fuels, fossil fuel consumption within the EU may release in the order of a further 150 tonnes per year into the environment which is comparable to a recent estimate that total anthropogenic emissions from the EU (and the three accession countries) are of the order of 160 tonnes per year.

Apart from anthropogenic sources of mercury, there are 'natural' releases from forest fires, volcanoes and 'evaporation' from the oceans. Within the EU, recent estimates suggest that 'natural' emissions within the EU may amount to 200 tonnes per year.

8.4 Predicting Environmental Concentrations

The behaviour of mercury in the environment is complex. Most releases are in elemental form to atmosphere which is then slowly oxidised to bivalent mercury (inorganic mercury). The inorganic mercury enters the terrestrial and aquatic environments through deposition. A portion of the inorganic mercury is methylated (particularly within sediments) to produce methyl mercury (organic mercury) which enters the water column.

Extensive research is ongoing into the precise reactions (physical, chemical and biological) which govern the rates of transformation amongst the three main forms of mercury in the different environmental compartments. There is, however, a general consensus that the key concern is organic mercury, which is highly toxic and bio-accumulates - particularly in fish.

For this study, the *EUSES* model was used (with some modifications) to predict mercury concentrations in the three main environmental compartments. In essence, the model was run twice:

- Run 1: 100% of emissions considered to be as elemental mercury in order to obtain predictions for the atmospheric compartment; and
- Run 2: 100% of emissions considered to be as inorganic mercury (mercuric chloride) to obtain predictions for the terrestrial and aquatic compartments.

The key inputs to the *EUSES* model were emissions (derived from an analysis of mercury production, product manufacture, product use and subsequent recovery or disposal) and toxicity data for humans and the environment. It was assumed, as a worst case, that the organic mercury concentrations would be 10% of the inorganic mercury concentrations.

The PECs (predicted environmental concentrations) for each compartment showed that the products' use, their manufacture and the production of the associated mercury contributed a percent to typical existing concentrations at continental level. At a regional level, the contribution was higher.

At a 'local' level (i.e. close to production facilities), significant air concentrations (elemental mercury) were predicted close to the primary production site in Spain. Otherwise, local values were very close to the regional values.

8.5 Risks Associated with Products under Study

Typical intakes of mercury are of the order of 10 µg/day. About 75% is elemental and inorganic mercury, most of which is associated with the inhalation of vapours from dental amalgam used in fillings. The remaining 25% is organic mercury (primarily methyl mercury in fish and fish products). For this study, reference doses of 2.0 and 0.1 µg per kg of bodyweight per day have been used as 'safe' levels for inorganic (including elemental) and organic mercury respectively. The 'margin of safety' (MOS) values can then be derived for the typical EU adult intake of 10 µg/day as follows:

for inorganic mercury,

- intake = 7.5 µg/day = 0.11 µg/kg bw/day (for a 65 kg adult);
- 'safe' level = 2.0 µg/kg bw/day; and
- therefore, MOS = 2.0/0.11 = 18 (in other words, daily intake is 18 times below safe levels)

for organic mercury,

- intake = 2.5 µg/day = 0.04 µg/kg bw per day (for a 65 kg adult);
- 'safe' level = 0.1 µg/ kg bw/day; and
- therefore, MOS = 0.1/0.04 = 2.5 (in other words, daily intake is 2.5 times below safe levels)

At a regional level, MOS values associated with elemental and inorganic mercury were found to be in excess of 100 (i.e. mercury intake is more than 100 times below 'safe' levels) whilst the MOS value for organic mercury was 18.

At a local level, MOS values associated with elemental mercury and inorganic mercury were generally found to be in excess of 100 although the higher atmospheric emissions close to the primary production site in Spain led to an MOS value of 6.5 and that for lamp production was found to be 55. For organic mercury, the local MOS values were essentially the same as the regional value (18).

In terms of risks to the environment, the criterion of importance is the ratio of the predicted environmental concentration (PEC) to the predicted no-effect concentration (PNEC). PEC/PNEC ratios of greater than unity are indicators that there may be a risk of concern and these were calculated at both regional and local levels.

PEC/PNEC ratios were derived for water, sediment, soil and (local) secondary poisoning (poisoning through the predatory food chain). The key findings may be summarised as follows:

- for water, the PEC/PNEC ratios for inorganic and organic mercury were significantly less than unity;
- for sediment, the PEC/PNEC ratios were significantly less than unity for inorganic mercury whilst those for organic mercury were in the range 0.2 - 0.4;
- for soil, the PEC/PNEC ratios for inorganic mercury were about 0.2; and
- for secondary poisoning, the PEC/PNEC ratios were significantly less than unity for the terrestrial food chain (inorganic mercury) whilst those for the aquatic food chain (organic mercury) approached unity (0.9).

8.6 Recommendations

Overall, using the TGD/*EUSES* approach (with modifications), it would appear that there are unlikely to be significant risks to the environment associated with the mercury containing products under study - with particular reference to dental amalgam, batteries, lamps, measuring and electrical equipment. Of the products under study, the key contributor is dental amalgam, which accounts for over half of the mercury used.

The modelling results suggest that the risks are primarily associated with organic mercury. However, given the complexity of the behaviour of mercury in the environment, the modelling has necessitated simplifying assumptions which clearly introduces a degree of uncertainty. Furthermore, changes to some critical parameters (such as partition coefficients) can make significant changes to the results.

Nevertheless, in accordance with the TGD, the results suggest a Conclusion (ii) which states that *there is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already*. To

this, could be added *or are already planned*, since there are a number of Directives (Water Framework Directive, RoHS Directive, ELV Directive, etc.) which will lead to further controls on the usage and emissions of mercury.

However, it is recognised that there is widespread concern over the presence of mercury in the environment and a desire to further limit the potential impacts of mercury usage. Of the estimated 160 tonnes per year of mercury emitted to the environment from anthropogenic sources in the EU and the three accession countries, the products under study account for less than 25 tonnes per year. There may, however, be areas where further reductions could be achieved in usage and/or associated emissions across the range of products examined here. Such reductions should be proportional to the relative emissions within the context of the overall anthropogenic use of mercury and the associated emissions.

In relation to the products under study, dental amalgam is the largest use with over 10 tonnes per year of mercury being emitted to the environment. The dominant source of emissions is releases from crematoria and this may be an area for further investigation. Measuring and control equipment would also appear to be a key source with emissions of 8.5 tonnes per year - primarily to the atmosphere from landfills. Within this sector, there may be areas where usage and/or emissions could be reduced. The other three products areas (batteries, lighting and electrical equipment) have significantly lower usage and emissions.

More generally, it is worth noting that the production of skin lightening creams involves the consumption of mercury in greater quantities than those used for measuring and control equipment - although this may be an area where more enforcement rather than more controls is required.

It is important to stress that any proposed controls would need a further investigation of the advantages and drawbacks under the requirements of the Marketing and Use Directive (76/769/EEC).

Finally, it is recommended that consideration should be given to classification and labelling under Directive 67/548/EEC based upon the developmental toxicity of methyl mercury and, perhaps, of other organic mercury compounds.

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ANNEX 1

TECHNICAL SPECIFICATION FOR STUDY

Extract from Tender Documentation:

4. TECHNICAL SPECIFICATIONS

4.1. INTRODUCTION - CONTEXT OF THE CONTRACT

The reduction of risks to human health and the environment related to the use of mercury has been an objective of a wide range of regulations in the European Union. There are several Directives setting emission standards for industrial and other combustion plants or immission standards for water quality. In addition, there are specific rules governing the use of mercury in specific applications or products, e.g. Council directive 82/176/EEC on limit values and objectives for mercury discharges by the chlor-alkali electrolysis industry, Directive 89/677/EEC on the use of mercury in paint and Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances (adapted to technical progress by Commission Directive 98/101/EC). Further limitations for the marketing and use of certain products containing mercury are under consideration. Some Member States, namely Denmark and Sweden have initiated a more comprehensive phase-out of mercury in products on a national level. A recent Commission Proposal for a Council Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment takes a similar orientation for that sector on Community level. The requirements under this proposed Directive are to be reviewed by the Commission by 1 January 2004 to take into account new scientific evidence.

The regulatory measures and efforts from industry to substitute mercury have led to a sharp reduction in the use of this metal and this process of substitution is expected to continue.

Against this background, the study will contribute to a better empirical and scientific basis for the future discussions on the possible need for further restrictions on the use of mercury.

4.2. Objectives, tasks, requirements and information

4.2.1. Objectives

The aim of the study is to up-date earlier studies (see 4.2.2.) on the risks to health and the environment posed by mercury in certain products. All stages of the life cycle should be taken into account including e.g. production, formulation, use, and disposal. While the study is to focus on present use of mercury in products, it should also examine to which extent mercury concentrations measured (particularly in the waste-stream) at present are influenced by former uses and non-anthropogenic sources. The study should also assess the relative risks from mercury in products compared with the other sources of mercury.

It is mandatory to complete the study within the time period specified under point 1.3.

4.2.2. Approach and tasks

The methodology of the study should be based on the Technical Guidance Document in support of Commission Regulation (EC) No. 1488/94 on risk assessments of existing substances (ISBN 92-827-8011 to 8014), however, taking recent developments of methodologies for risk assessment of metals and the particular behaviour of mercury in the environment into account.

Tasks

The study should adapt, up-date and extend an earlier assessment of the risks to health and the environment from mercury in certain products[1] and use data contained in the pertaining study on advantages add drawbacks on marketing and use of certain products containing mercury[2]. In general, it is to be based on recent data in order to take account of the potential results of reduced mercury use. The scope of products is to be widened to batteries and consider the impact of policy measures taken in that field. The geographic area investigated is to include the Poland, the Czech Republic and Slovenia to the extent where data are available.

Particular attention will be paid to the following points:

- Human toxicity. The evaluation of toxicity to humans should be expanded and take recent information into account.

- Derivation of PEC (Predicted Environmental Concentration) values. The derivation of PEC values should be revised with regard to methodology and based to the extent possible on monitored data.

- Derivation of PNEC (Predicted No Effect Concentration) values. The derivation of PNEC values should be revised especially with regard to data used, aiming at an application of the probabilistic method.

- Risk characterisation. The risk characterisation should be revised and could be further improved by addressing the effects of environmental characteristics of mercury toxicity and by the inclusion of PNEC values adapted to the water/soil conditions using probabilistic approaches for European water/soil characteristics.

- The study should also assess the relative risks from mercury currently used in products in the European Union as compared with the other sources of mercury (non-product use, natural, historical,). In this context the study should also discuss the potential influence of different use patterns of mercury outside the Union (imports via products and transboundary pollution).

[1] Assessment of the Risks to Health and the Environment of Mercury in Certain Products, WS Atkins, Final Report, August 1998.

[2] Analysis of the Advantages and Drawbacks of Restricting the Marketing and Use of Mercury in Certain Products, Environmental Resources Management (ERM), December 1998.

ANNEX 2

LIST OF CONSULTEES

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Department for the Environment, Food & Rural Affairs (UK)
Dutch Ministry of Housing, Spatial Planning and the Environment
European Committee of Domestic Equipment Manufacturers (CECED)
European Lighting Companies Federation
FDI World Dental Association
Finnish Dental Association
French Ministry of Spatial Planning and the Environment
French National Institute of Research and Safety (INRS)
Fujitsu Components Europe BV (Netherlands)
Gascoigne-Melotte (Belgium)
GE Lighting
Hella KG Huck & Co (Germany)
Hellenic Dental Association
Henry Schein
HI Instruments (Finland)
Instituto Superiore di Sanito (Italy)
International Archery Association
International Council for Mining & Metals
International Zinc Association
Irish Health and Safety Authority
James Scientific Instruments Ltd (UK)
Lead Development Association
Mater Health Trust (Northern Ireland - UK)
MAYASA
Medical Devices Agency (UK)
Mercury Recycling Ltd
Miele (Germany)
NHS English Purchase and Supply Agency (UK)
Odin Research & Development
Omron Electronics Europe
Ordem dos Médicos Dentistas (Portugal)
Osram (Siemens)

Philips
Polamp-Warsaw
Quicks Archery (UK)
Ragim SrL (Italy)
RIVM (Netherlands)
Rota-Dent Ltd (UK)
Russell Scientific Instruments (UK)
S Brannan & Sons Ltd
Southern Dental Industries (SDI)
Shermond Surgical Supply Ltd (UK)
Siemens AG
Société de Médecine Dentaire (Belgium)
Star Refining plc
Swedish Environmental Protection Agency
Swedish Federation of County Councils
Swedish National Chemicals Inspectorate (KemI)
Syndicat de al Measur (France)
Tridonic (Austria)
UNEP (Global Mercury Assessment)
Universal Hospital Supplies Ltd (UK)
Westfalia (Germany)

In addition, we would like to acknowledge the assistance provided by a number of further companies which asked not to be named.

ANNEX 3

LIST OF MERCURY CONTAINING PRODUCTS

Source: Original data presented in Gilkeson J (1996): **Mercury Products Study**, report for the Minnesota Pollution Control Agency dated April 1996 (and revised August 1998) as reproduced in Land & Water Resources Council (1999): **Labeling and Collection of Mercury-Added Products**, report for the Maine Legislature dated January 1999.

Uses of mercury for its mechanical properties as a high-density, low-friction fluid

- telescope mirrors
- Canter Tube: 6' tube used in medical procedures to trace GI tract
- Bougie Tube: used in medical procedures for esophageal dilation
- lighthouse lamp bearing
- waste water treatment plant pivot arm bearing
- archery as a bow stabilizer; two models: 6" 8 oz.; 10" 11 oz. (Neutralizer®)
- DC watt hour meters (no longer made but may still be in use)
- bubbler or trap used in laboratories to seal reaction vessels for monitoring gas evolution
- weights and counterweights in grandfather clocks

Pressure and flow rate measurement and control devices (manometers), tube type and well type Note: devices in this category have extensive application in the natural gas industry

- sphygmomanometers (blood pressure "cuffs")
- laboratory manometers (pressure measurement devices)
- commercial-industrial manometers (many types and uses)
- dairy barn manometers (tube type, measures milking system vacuum)
- barometers - atmospheric pressure (well type, climatology and meteorology uses)
- gas meter pressure safety device (tube device, likely no longer made but in use)
- permeter - used to measure permeability of sand mass to flow of air (foundry application)
- air flow measurement devices using a Pitot Tube and manometer (foundry and other applications; may also be called an airway controller)
- mercury diffusion pump (laboratory/educational use)

Temperature measurement and sensing devices

- Mercury in glass thermometers, (ASTM and laboratory)
  - cup case (for tank sample temperature testing)
  - tapered bulb thermometers (armored)
  - sling psychrometer (for measuring relative humidity)
  - mason's hygrometer (stationary, for measuring relative humidity)
  - oven temperature control (home and commercial)
  - candy/deep-fry thermometers (home and commercial)
  - weather measurement thermometers (home, commercial, scientific)
  - minimum/maximum thermometers (home, commercial, scientific)
  - fever thermometers (home, commercial, veterinary)
  - other specialty uses, e.g., Clerget sugar test, blood bank, incubator/water bath, dairy
- Mercury flame sensor/mercury safety valve (stainless steel bulb, capillary tube, and bellows control device) used for 'unsupervised burners' in certain gas fired devices with standing pilot or electronic ignition pilot , e.g., residential and commercial 0vens/ranges, commercial griddle with concealed pilot, unit heaters, some light industrial oven applications, furnaces, infrared heaters, 'cycle pilot' devices)
- Mercury thermostat sensors (w/stainless steel capillary tube) (used in gas ovens operating up to 750°F (not used in self-cleaning ovens), discontinued in 1970's. Currently produced devices use oil or sodium-potassium mixture.)

Thermo-electric devices (mercury movement opens and closes an electrical circuit at a preset or adjustable set point)

- thermostats (1, 2 or 4 glass tubes of mercury are used in conjunction with relay control device); mercury-thallium models are used for temperatures to neg. 60°C

- thermal switch with integral or remote mounted solid state control (similar to a thermostat)
- thermoregulator (an adjustable mercury in glass device with an electrical output dependent on the position of the mercury column)

Electrical properties (switches, relays, sensors)

- cathode in mercury-cell chloralkali production facilities
- dropping mercury electrode (DME) technique for polarography and analytical chemistry
- displacement or plunger relays (generally for high current, high voltage applications, e.g., resistance heating, welding, lighting, power supply switching, and industrial process controllers
- wetted reed relays (printed circuit board mount) - primarily used in test, calibration, measurement equipment where stable contact resistance over the life of the product is necessary. One industry source states that 90% of market is for specialized equipment produced in quantities of 10-200 units per year; mass production applications do not need mercury-wetted reed relays
- telecommunications industry switching equipment and boards used in central facilities
- tilt switches (including SPST, SPDT, NO, NC, wide angle, omni-directional, circuit board mount)
    - temperature control (mounted on bimetal coil or attached to bulb device)
    - pressure control (mounted on bourdon tube or on diaphragm)
    - fluid level control (mounted in float, on lever arm, on diaphragm or on plunger)
    - airflow/fan limit controls (mounted to vane in airflow)
    - pneumatic tube communication systems
    - 'man down' alarms
    - swimming pool alarms
    - safety shut off
        - steam irons
        - electric space heaters (may have been discontinued by early 1995)
        - outboard motors
        - limit switches for industrial machinery
    - automobile hood, trunk, vanity mirror, glove box, emergency brake lights
    - automobile automatic roll bar
    - automobile 'ride control' automatic leveling suspension
    - automobile security systems (tilt and trembler devices)
    - building security systems (tilt and trembler devices)
    - 'silent' wall switches, single pole and three-way; identifiable by "top" mark on one end of switch (discontinued by GE in 1991; Leviton only other reported manufacturers)
    - commercial popcorn poppers
    - film editing equipment
    - greenhouse louver positioning devices
    - washing machine spin cycle shut-off (no longer in production)
    - chest freezer lid light
    - security system applications (including automobile, computer and other applications where movement of a 'momentary contact' switch triggers an alarm)
    - anti-tamper device in gas meters and pay phones (unable to confirm gas meter application with major gas meter manufacturer)

  - automatic car washes (Ryko: treadle on/off switch and detection of top brush position)
  - ice fishing tip-up lights
  - fishing lure (manufactured in Canada possibly for tip-ups)
  - lawn tractor/riding mower fuel level indicator
  - electric organs - non-keyboard controls such as tone
  - fire alarm box switch
  - marine auto-pilot
  - level and rotation sensors and controls (automobile, aircraft, and defense applications)
  - laptop computer - screen shutoff when cover closed
  - portable phone mute/privacy switch when phone is in horizontal position
  - cameras (still, video, film); overridable position sensor to protect from sunlight damage
- proximity sensors, magnetically activated, applications unknown
- g-sensors
  - automobile ABS sensors (used to pulse system and disengage auto 4wd)
  - some older automobile air bag sensors
  - auto seat belt mechanisms (electrically activated inertia lock)
  - security system applications
- rectifiers, oscillators, phanatrons, thyratrons, ignitrons, excitrons, cathode tubes; inverters
- switches or relays in some remote reading devices for utility meters, purpose unknown

Electrical Discharge Properties/Lighting

- fluorescent lamps: general purpose straight, U-bent, circline, compact high output, bilirubin blue, blacklight, "bug-zapper" devices
- high intensity discharge
  - mercury vapor lamps
  - high pressure sodium lamps
  - metal halide lamps used in automobile headlights (new use, xenon-mercury-halide)
  - 'CS - compact source mercury lamps' (photographic, lab uses)
  - 'Special mercury lamps' (UV properties)
- neon lamps (most colors except red, orange, pink)
- spectral lamps - monochromatic light source for laboratory and research applications
- cold cathode lamps for illumination
- germicidal lamps (hot cathode, cold cathode, slimline)

Electronic Properties/Semiconductors

- mercury-cadmium telluride semiconductors/infrared sensors Extensive defense and satellite uses; no substitute with comparable performance for many applications. One researcher estimates annual mercury consumption for this use at 100 pounds. Includes photovoltaic and photoconductive cells.

Medical, pharmaceutical, cosmetic/human contact

- vaccines and other biologic products
- homeopathic medications (at least 17 compounds used, many applications)
- over-the-counter (OTC) nasal sprays (preservative)
- OTC ophthalmic and contact lens products (preservative)
- eye-area cosmetics (up to 65 ppm mercury) (preservative)
- hemorrhoid ointments and creams (preservative, discontinued early 1995)
- OTC disinfectants: Mercurochrome® [merbromin], tincture of merthiolate
- merbromin solution used in plastic reconstructive surgery as disinfectant and marker

- mercuric chloride peritoneal lavage in cancer surgery (Great Britain)
- skin bleaching creams (OTC discontinued in US by early 1970s)
- diuretic (mersalyl and salts are still manufactured, extent of use unknown)
- traditional Chinese medicine (including herbal balls)
- spiritist use
- tattoo pigments (discontinued in US, likely in 1970's)

Medical and laboratory/no human contact (active ingredient or preservative)

- tissue fixatives for pathology, histology (e.g., Zanker's, B5)
- tissue stains (Harris hematoxylin stain may be mercury-free)
- Hayem diluting fluid for red blood cell count) contains mercuric chloride
- reagents for various diagnostic and laboratory tests:
  - arsenic-calcium reagent (260 ppm)
  - Precision reagent (240 ppm)
  - CPK reagent (2.7 ppm)
  - colorimetric chloride analysis (mercuric thiocyanate or mercuric nitrate titration)
  - Nessler's Reagent/Channing's Solution (mercury potassium iodide); used for total
  - Kjeldahl nitrogen (no apparent alternate method) and nitrogen ammonia (USEPA
  - accepted/approved).
  - Millon's Reagent (mercury-nitric acid solution, for albumin)
  - salinity (mercuric nitrate titration)
- Radiometer (brand) blood gas analyzer reference electrode
- ESA (brand) Model 3010B Lead Analyzer electrode (used for testing blood lead levels)
- preservative in various products such as pregnancy test kits and possibly in similar diagnostic products
- thimerosal used as preservative for sucrose buffers in disc electrophoresis

Veterinary medicine and other veterinary/livestock uses:

- vaccines for cattle, swine, and dogs
- other medications:
  - Dip-A-Way (contains merbromin, mfd. by Universal Aquarium System)
  - Wound Control (contains merbromin, mfd. by Universal Aquarium System)
  - RX ICK Control (contains merbromin, mfd. by Wardley Corp.)
  - Aqueous Red Mercury Blister (contains mercuric iodide; mfd by QA Laboratories and P.C. Laboratories)
  - Phillips Corona Ointment antiseptic dressing for horses and other animals
- udder wash with thimerosal - discontinued many years ago

Pesticides

- food uses canceled in 1969 and US pesticide registrations canceled by early 1995. Last four uses to be canceled were as a turf fungicide, a mildewcide for fresh cut wood, a fungicide and preservative in latex paint, and outdoor fabric treatment
- marine anti-fouling paint (discontinued in 1970's)

Pigments (reds and oranges)

- Used in engineering plastics where high temperature stability is required. Past uses included many automotive parts, vinyl, ABS, polycarbonate. The only remaining manufacturer is SLMC in France; one US auto manufacturer reports recently

discontinuing a mercury containing color concentrate used in plastic component manufacturing.

Catalysts (primarily for urethane and vinyl)

- polymer curing
- monomer production
- acetylene production (probably no longer used)
- vinyl and anthraquinone production (unconfirmed)
- Battery electrodes (mercuric oxide battery, mercury-cadmium battery)

Other uses

- battery anti-gassing (zinc anode coating in alkaline, carbon zinc batteries)
- fireworks (no longer used by US manufacturers but may be used elsewhere)
- Explosives: mercury fulminate, apparently no longer manufactured
- School laboratory experiments and demonstrations
  Note: this use is prone to mismanagement and release, and generates hazardous nonrecyclable waste; chemical principles and phenomena can be demonstrated with less toxic or non-toxic substances.

Amalgamating properties and amalgams

- dental
- gold mining/extraction (used in small scale artisanal' mining, large scale mining reportedly uses other chemical or mechanical processes)
- mirror silvering (discontinued about 1900)
- gold porcelain paint (availability and use in US unconfirmed)
- gun cleaning: mercury is poured into the barrel and then removed, reportedly to remove lead, copper and brass residues

Home uses that have resulted in documented mercury poisoning (a sampling)

- fabrication of fishing sinkers with mercury, lead, copper, and solder (heating)
- gold smelting (heating)
- recovery of silver from dental amalgam (heating)
- recovery of mercury from products such as batteries (heating)
- use of interior latex paints with high mercury preservative levels
- vapor exposure from spilled mercury and broken products such as thermometers
- consumption of treated grain or meat from animals fed treated grain
- fluorescent lamp breakage/acrodynia in 2 year old (ingestion/inhalation)
- use of 'folk' medicines containing mercury (ingestion/inhalation/dermal contact)
- use of a beauty cream containing calomel (mercurous chloride)
  Note: mercury poisoning from use of the cream ("Crema de Belleza' made in Mexico) was documented in individuals in California, New Mexico and Texas in 1995 and 1996. Total mercury content of the cream was 6 to 8%.

ANNEX 4

ANALYSIS OF *AQUIRE* DATA FOR CONSISTENCY

A4.1 Introduction

This annex provides a brief description of an analysis of mercuric chloride toxic effects data for freshwater and saltwater taxa using data from the USEPA *AQUIRE* database. These data are analysed in both the standard TGD fashion, by selecting the most sensitive results in three taxonomic groups, and by using the statistical extrapolation methodology of Aldenberg & Slob (1993), which is also allowed under the TGD. Results based on *AQUIRE* data are then compared with those presented by Eurochlor in two reports from 1999.

A4.2 Analysis of Data from *AQUIRE*

A4.2.1 LC_{50} Data

AQUIRE was searched for lethal and sublethal data on mercuric chloride.

1197 data entries were found. These were separated into freshwater and saltwater species and the data for each species were consolidated. First, the most sensitive time period was found. Then, if more than one result for this time period was available for the same species, the geometric mean of these results was calculated. LC_{50} data (or EC_{50} data for lethality surrogates such as immobility) were available for 141 freshwater and 64 saltwater species.

Freshwater Data

The most sensitive freshwater LC_{50} data were:

- algae: *Chlorella vulgaris* 12-d EC_{50} of 128 µg/l;
- invertebrates: *Bosmina longirostris* (waterflea) 96-h LC_{50} of 0.55 µg/l. The standard European test species *Daphnia magna* had a 21-d LC_{50} of 8.06 µg/l; and
- fish or amphibians: the most sensitive species in the LC_{50} toxicity distribution was the clawed toad *Xenopus laevis*, with a 7-d LC_{50} of 0.16 µg/l. The next most sensitive species was a fish, the channel catfish, *Ictalurus punctatus*, with a 4-d post-hatch LC_{50} of 0.3 µg/l. The standard European test species *Oncorhynchus mykiss* (rainbow trout) had a 4-d post hatch LC_{50} of 0.69 µg/l.

These data show that crustaceans, amphibians and the early life stages of fish are the most sensitive to mercuric chloride lethal toxicity.

Saltwater Data

The most sensitive saltwater LC_{50} data were:

- algae: No standard European saltwater algal species results were reported on the *AQUIRE* database, but a 96-h EC_{50} of 4.0 µg/l was reported for the dinoflagellate *Gonyaulax polyedra*;.

- invertebrates: The mollusc *Villorita cyprinoides cochi* was the most sensitive saltwater species, with a 96-h LC_{50} of 1.57 µg/l. The standard North American mysid shrimp test species, *Americamysis bahia*, was the next most sensitive, with a 35-d LC_{50} of 1.8 µg/l. A 24-h EC_{50} of 13 µg/l was found for the Pacific oyster *Crassostrea gigas*, a species often used in European risk assessments; and
- fish: The most sensitive saltwater fish species found on the *AQUIRE* database was the spot, *Leiostomus xanthurus*, with a 96-h LC_{50} of 36 µg/l.

These data show that invertebrates were the most sensitive species tested. However, early life stage tests with fish species are missing, so the relative insensitivity of saltwater fish may be an artefact.

Statistical Extrapolation for LC_{50} Data

A logistic distribution fitted the freshwater LC_{50} toxicity data and the Aldenberg & Slob (1993) statistical extrapolation method estimated a median HC5 (Hazardous Concentration to 5% of Species) of 3.4 µg/l, with a lower 95% confidence limit (95% CL) on the HC5 of 1.8 µg/l. A logistic distribution also fitted the saltwater data well. The Aldenberg & Slob (1993) approach produced estimated median HC5 and lower 95% CL values of 4.7 and 2.5 µg/l respectively.

A4.2.2 Sublethal Data

There were far fewer sublethal data available in *AQUIRE*, and most of these were EC_{50} values for sublethal responses, rather than NOEC or LOEC values. These data were treated in the same way as the LC_{50} data, with the additional criteria that only the most sensitive endpoint was selected for each species (e.g., reproduction or growth) and results should be reported as mass per litre. Only endpoints of direct demographic relevance (i.e., growth and reproduction) were selected for analysis. Sublethal data meeting the above criteria were found for 32 different freshwater and saltwater species.

Freshwater Data

The most sensitive sublethal freshwater data were:

- algae: a population growth rate LOEC of 5 µg/l for the blue-green alga *Microcystis aeruginosa*;
- invertebrates: a 21-d reproduction EC_{50} of 6.7 µg/l for the waterflea *Daphnia magna*; and
- fish: none found.

Saltwater Data

The most sensitive sublethal saltwater data were:

- algae: a 5-d growth EC_{50} of 10 µg/l for the diatom *Ditylum brightwellii*;

- invertebrates: an 11-d population change LOEC of 1.65 µg/l for the saltwater hydroid *Campanularis flexuosa*; and
- fish: a 32-d hatching success EC_{50} of 37.18 µg/l for the mummichog *Fundulus heteroclitus*.

These most sensitive chronic data either do not differ substantially from the most sensitive acute data, or tend to be slightly higher, which may reflect either a low acute to chronic ratio or the paucity of chronic data on the *AQUIRE* database. There is also some confusion in the reporting of the algal data: it is likely that data in both the LC_{50} and the sublethal categories are from similar types of experiment on population growth rate, but have been reported differently on the database. This has no effect on an overall analysis of the data.

Statistical Extrapolation of Sublethal Data

Because of the relatively low number of data, freshwater and saltwater data were analysed together to estimate an HC5 according to the Aldenberg & Slob (1993) method. The data fitted a logistic distribution, with a median HC5 value of 1.8 µg/l and a lower 95% CL of 0.45 µg/l.

A4.3 Comparison of Results with Eurochlor

The results reported above were then compared with those from the Eurochlor reports (Eurochlor, 1999 & 1999a). The following points emerge:

- Eurochlor followed the recommendations of the Technical Guidance Document (TGD) and concentrated on 'chronic' (i.e., long-term exposure) data. The *AQUIRE* database contained more data on lethal effects than those reported by Eurochlor, but fewer useful data on long-term effects;
- Eurochlor divided mercury compounds into two categories: organic and inorganic, while we divided inorganic mercury into specific salts, such as mercuric chloride as reported here; and
- there are some inconsistencies in the use of terminology between the Eurochlor report and our analysis. Eurochlor separate tests into LC_{50}/EC_{50} and LOEC/NOEC results. We separated tests into lethal and sublethal results. However, in the overall analysis this distinction does not affect any conclusions drawn from either of the separate analyses.

Conclusions on Most Sensitive Test Results for Different Taxonomic Groups

Comparison of Eurochlor inorganic mercury conclusions and the results of this analysis suggest the following:

- freshwater fish: Eurochlor found that the most sensitive lethality study was a 96-h LC_{50} of 26 µg/l for the guppy, *Poecilia reticulata*. In our analysis the channel catfish, *Ictalurus punctatus*, with a 4-d post-hatch LC_{50} of 0.3 µg/l, and

Oncorhynchus mykiss (rainbow trout) with a 4-d post hatch LC_{50} of 0.69 µg/l showed the most sensitive lethality results. However, the most sensitive vertebrate was the clawed toad *Xenopus laevis*, with a 7-d LC_{50} of 0.16 µg/l. Eurochlor found that the most sensitive chronic result was a 41 week growth and reproduction NOEC of 0.5 µg/l for the fathead minnow *Pimephales promelas*. Our analysis did not find any useful chronic freshwater fish data;

- saltwater fish: Eurochlor found that the most sensitive lethality study was a 96-h LC_{50} of 67 µg/l for the mummichog, *Fundulus heteroclitus*. In our analysis the spot, *Leiostomus xanthurus*, was the most sensitive, with a 96-h LC_{50} of 36 µg/l. Eurochlor found that the most sensitive chronic study was a 32-d reproduction NOEC of 10 µg/l with the mummichog. Our analysis found a 32-d hatching success EC_{50} of 37 µg/l for the same species;
- freshwater invertebrates: Eurochlor found that the most sensitive lethality value was a 96-h LC_{50} of 1 µg/l for the crustacean *Crangonyx pseudogracilis*. In our analysis, the waterflea *Bosmina longirostris* was the most sensitive, with a 96-h LC_{50} of 0.55 µg/l. Eurochlor found that the most sensitive chronic result was a 10 week reproduction NOEC of 0.62 µg/l for the crustacean *Hyalella azteca*. Our analysis found that the most sensitive result was a 21-d reproduction EC_{50} of 6.7 µg/l for the waterflea *Daphnia magna*;
- saltwater invertebrates: Eurochlor found that the most sensitive lethality study was a 96-h LC_{50} of 10 µg/l with the copepod *Acartia tonsa*. In our analysis the mollusc *Villorita cyprinoides cochi* was the most sensitive saltwater species, with a 96-h LC_{50} of 1.57 µg/l. The standard North American mysid shrimp test species, *Americamysis bahia*, was the next most sensitive, with a 35-d LC_{50} of 1.8 µg/l. Eurochlor found that the most sensitive chronic studies were a 112-d reproduction NOEC of 0.25 µg/l with the mollusc *Crepidula fornicata* and a 44-d reproduction NOEC of 0.8 µg/l for the crustacean *Americamysis bahia*. Our analysis found that an 11-d population change LOEC of 1.65 µg/l for the saltwater hydroid *Campanularis flexuosa* was the most sensitive;
- freshwater algae: Eurochlor found that the most sensitive short-term result was 9 µg/l for a static 96-h EC_{50} with *Selenastrum capricornutum*. In our analysis the most sensitive result was a 12-d EC_{50} of 128 µg/l with *Chlorella vulgaris*. Eurochlor found that the most sensitive longer-term result was an 8-d LOEC of 5 µg/l with *Microcystis aeruginosa*. Our analysis agreed with Eurochlor's; and
- saltwater algae: Eurochlor found that the most sensitive short-term result was a 5-d EC_{50} of 10 µg/l for the diatom *Ditylum brightwellii*. Our analysis found a 96-h EC_{50} of 4.0 µg/l for the dinoflagellate *Gonyaulax polyedra*. Eurochlor found that the most sensitive longer-term results were a 10-d growth NOEC of 0.9 µg/l for *Fucus serratus* and a 13-d growth LOEC of 0.77 µg/l for *Isochrysis galbana*. Our analysis found a 5-d growth EC_{50} of 10 µg/l for the diatom *Ditylum brightwellii*.

Comparison of Results Based Upon a Safety Factor Approach

Eurochlor uses a safety factor approach to predict a safe concentration for inorganic mercury of 0.025 µg/l. This is based upon long-term NOEC data from at least three species representing three trophic levels, and a safety factor of 10. The important

datum in this set is the 112-d reproduction NOEC of 0.25 µg/l for *Crepidula fornicata*, found by Thain (1984 - as reported in Eurochlor, 1999a).

Using the same approach with data from the *AQUIRE* database suggests a safe concentration for mercuric chloride of 0.165 µg/l based upon an 11-d population change LOEC of 1.65 µg/l for the saltwater hydroid *Campanularis flexuosa,* found by Moore & Stebbing (1976[1]). However, caution must be exercised as this is a comparative value for this analysis only. This result is very close to LC_{50} values of 0.3 µg/l for channel catfish early life stages, and 0.69 µg/l for rainbow trout early life stages. It is also the same as the 7-d LC_{50} of 0.16 µg/l for the most sensitive vertebrate, the clawed toad *Xenopus laevis*.

Comparison of Results based upon Aldenberg & Slob Statistical Extrapolation

Eurochlor (using studies ascribed a validity of 1 or 2) predicted a PNEC of 0.47 µg/l. Our comparative analysis (using all freshwater LC_{50}/EC_{50} data, all saltwater LC_{50}/EC_{50} data, and all 'chronic' sublethal data) estimated HC5s (Hazardous Concentration to 5% of Species) of 3.4 µg/l (with a lower 95% confidence level (CL) of 1.8 µg/l), 4.7 µg/l (lower 95% CL = 2.5 µg/l) and 1.8 µg/l (lower 95% CL = 0.45 µg/l) respectively.

As can be seen, the lower 95% CL for the HC5 derived from the chronic data is very close to the PNEC estimated by Eurochlor.

A4.4 Overall Conclusions

The results presented here for mercuric chloride from the *AQUIRE* database compare well with the results Eurochlor found for all inorganic mercury salts. As such, it is considered 'safe' to use the data provided by Eurochlor (1999a) and INERIS (2000) in this analysis. Where additional data are available from other reliable data-bases, such as *AQUIRE*, these will also be used.

[1] Moore MN & Stebbing ARD (1976): *The Quantitative Cytochemical Effects of Three Metal Ions on a Lysosomal Hydrolase of a Hydroid,* J.Mar.Biol.Assoc.U.K Vol 56 pp 995-1005.