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Mass flow analysis of mercury 2001

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Contents

Foreword

The overall goal of this mass flow analysis is to update our present knowledge of the use, consumption and dispersal of mercury in Denmark. The previous mass flow analysis of mercury covered the period 1992-1993.

This project was financed by the Danish Environmental Protection Agency (Danish EPA) and has been observed by an observation group consisting of:

- Henri Heron, Danish EPA (chairman)
- Poul Erik Andersen, National Working Environment Authority
- Mette Herget, HTS (Danish Chamber of Commerce)
- Henning Fokdal, Confederation of Danish Industries
- Carsten Lassen, COWI.

During the course of this mass flow analysis, information was obtained from trade organisations, manufacturers, importers, the Department of Data on Chemical Products, know-how centres and public institutions, without whose obliging efforts this investigation could not have been conducted.

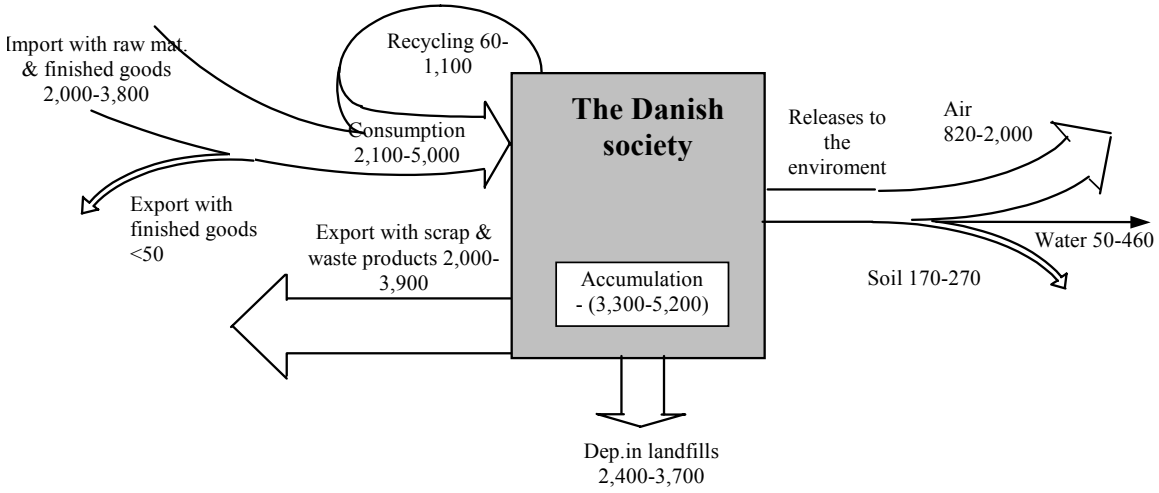
This mass flow analysis was conducted during the period April 2002 to the beginning of 2003. This report was prepared by a working group, which consisted of Susanne Skårup, Claus Lübeck Christensen, Susan Heilemann Jensen and Jakob Maag, COWI.

Summary and conclusions

A detailed account has been prepared of the consumption of mercury in Denmark, distributed by its various uses. The disposal of mercury and its release to the environment have also been quantified. This analysis has predominantly been based on data from 2001.

Mercury balance
Available information on, and estimates of consumption and releases to the environment of mercury in Denmark are illustrated in Fig. 1.

Fig. 1 Mercury balance for Denmark 2001 (all figures represent kg/year)



As shown in Fig. 1, the consumption of mercury is estimated at between 2,100 and 5,000 kg/yr, while imports of mercury and with mercury-containing products have been between 2,000 and 3,800 kg/yr, and exports with finished goods have been insignificant.

A more detailed presentation of the various areas of use is shown in Table 1, which is a simplification of Table 4.1, in the section entitled "Overall assessment" in this report.

Areas of use
The greatest intentional use of mercury is in the mercury amalgam used in dental fillings. This application corresponds to about 1/3 of the total consumption and 70-80% of the intentional consumption.

Lesser applications include light sources, batteries, thermometers, monitoring equipment, and laboratory chemicals. The total intentional consumption is estimated at about half of the total consumption.

The remainder of the total consumption is due to the unintentional "consumption" of mercury, e.g., as an impurity in coal and other goods and commodities.

Table 1
Consumption of mercury in Denmark

Product group	Consumption, 2001, kg Hg/yr	Percentage of total 2)
Metallic mercury		
Dental fillings	1,100-1,300	34
Light sources	60-170	3
Switches, contacts and relays	0-24	0
Thermometers	16-24	1
Monitoring equipment	10-50	1
Other uses as a metal	35-60	1
Chemical compounds		
Batteries	70-150	3
Laboratory chemicals	30-70	1
Medical applications	0-1	0
Other chemical uses	5-50	1
As an impurity		
Coal	600-1,000	23
Other products 1)	140-2,100	32
Total (rounded)	2,100-5,000	100

1) "Other products" includes oil, biological fuels, commercial fertilisers, agricultural lime, and other products in which mercury naturally occurs in low concentrations as a trace constituent or contaminant (at the ppb-level). The consumption of mercury in these applications can only be estimated with great uncertainty. See explanation of figures in Table 2.18.
2) Calculated as the average value of the listed consumption figures.

Development trends

The use of mercury is generally diminishing. Total mercury consumption has dropped to roughly 20% of the consumption in 1982-83. Consumption through the intentional uses of mercury has dropped to 10% of the consumption in 1982-83. The consumption has dropped to about 40% of that found in the previous mass flow analysis (i.e., for 1992-93, Maag et al., 1996), whereas the consumption through intentional uses has dropped to 25% of that in 1992-93. An additional drop in intentional uses can be expected in the future.

Despite the drop in most deliberate uses, it is worth noting that uses, in which consumption was previously heavy and which have been strictly regulated at the national and international levels, have logically enough become more marginal. In their place, uses that have not been exposed to the same regulatory pressure, and which have perhaps partly for that reason not developed to quite the same extent during the last decades, are now becoming apparent. For instance, dental fillings, button cell batteries of other types than those containing mercury oxide, and light sources.

It is also worth noting that the mobilisation and release of the mercury occurring as a trace element in coal continues to drop, primarily because Denmark is endeavouring to shift its energy production away from coal, in an effort to reduce emissions of carbon dioxide and a number of other pollutants.

Releases to the environment

Table 2, which is a simplified version of Table 4.4, offers an overview of releases of mercury to the environment.

Table 2
Releases of mercury to the Danish environment in 2001, kg/yr

Product/application	Estimated loss (kg/yr of mercury) to:				
	Air	Water	Soil	Deposition in landfills	Total (rounded)
Industrial processes					
Cement production	70-170	-	-	-	70-170
Other indust. activities 3)	1-12	4-86	0-10	52	57-160
Energy production					
Coal	190-310	-	-	68-110	260-420
Other fuels	22-110	4.7-6.7	1.2-5	7.9-23	36-140
Use of products					
Dental clinics	-	50-250 1)	-	-	50-250 2)
Thermometers	-	20-40 1)	-	-	20-40 2)
Miscellaneous	25-60	20-50 1)	13-40	-	58-150 2)
Waste management					
Waste incineration	270-1,000	-	-	2,000-2,900 4)	2,300-3,900
Municipal waste water/sludge	22-46	14-280	62-94	40-47	140-470
Miscellaneous	220-270	26-84	97-120	230-570	570-1,000
Total (rounded)	820-2,000	50-460	170-270	2,400-3,700	3,400-6,300

1) The listed quantities are discharged to wastewater from which, after treatment in a sewage treatment plant, the mercury will pass in part to sludge and in part to the treated water discharged from the plant. These quantities are therefore included in "Municipal wastewater/sludge" and have not been included a second time under "Total."
2) The listed quantities are only included in the summation to the extent that they are not included under other headings.
3) "Other industrial activities" include oil and gas extraction.
4) This is deposited in landfills outside Denmark.

Emissions to the atmosphere
The principal source of emissions to the atmosphere is waste incineration, which is considered to be heavily dependent on the mercury contained in batteries, electrical switches, contacts and relays, and dental fillings. Note however that it is difficult to account for the input to waste incineration with any certainty, as the quantities of mercury involved are on the low side of that recorded for the emissions of the incinerator plants.

The second largest sources of emissions to the atmosphere are coal-fired power stations, which are estimated to contribute an annual 190-310 kg of mercury, whereas cremations contribute an annual 170-190 kg of mercury.

Discharges to water
Discharges to water are dependent on the wastewater discharged by municipal sewage treatment plants, which is primarily impacted by the mercury discharged from dental clinics.

Releases to soil
Releases to soil are heavily dependent on wastewater sludge and cemeteries (dental fillings).

Losses to landfills
By far the greatest part of the mercury sent to landfills consists of the residual products of waste incineration. These products are sent to landfills outside Denmark.

Development trends
Emissions to the atmosphere have dropped to about 1/4 of the emissions in 1982-83. This is particularly due to the drop in emissions from waste incineration resulting from improved flue gas cleaning. In 2001 these emissions amounted to less than 2/3 of the emissions in 1992-93. This drop is related to a drop in emissions from the production of iron and steel, from coal combustion and from the disposal of light sources.

Discharges to water have dropped to about 1/5 of the level in 1982-83, but remain at the level of - or perhaps a little above - the discharges in 1992-93. The latter is due to the fact that discharges to the marine environment from offshore oil and gas extraction are included in the calculations for 2001.

Releases to soil have changed comparatively little since the survey for 1992-93. There has been a significant drop since 1982-83, this change is due to the fact that dressing seed corn with mercury has been phased out.

The increased use of waste incineration, combined with improved flue gas cleaning resulted in an increase in the quantity of mercury sent to landfills.

Collection and disposal/recycling
Considerable quantities of used mercury and mercury-containing waste are collected in Denmark. Thus, an annual 2-4 tonnes of mercury is collected with waste. This waste is exported.

Accumulation in Denmark
As can be seen from Fig. 1, these activities result in a negative annual accumulation of 3,300-5,200 kg of mercury in Denmark. In turn, this illustrates how mercury consumption is falling in Denmark, as well as the fact that the existing stores of mercury in Denmark (e.g., in electrical switches, contacts and relays in old telephones) are diminishing.

Stockpiling in Denmark
The total stock of mercury in Denmark was estimated at 50-250 tonnes for 1992-93. The negative accumulation at the same time was 3,100-7,900 kg of mercury/year. The total depletion of the stockpile during the period up to 2001 is not known with any certainty, but it probably constituted about 40 tonnes, so that the present mercury stockpile is of the order of 10-210 tonnes. The continuing flows of mercury to disposal indicate that the accumulated quantity of mercury in Denmark possibly was underestimated originally, and that the "detoxification" of the country will therefore take longer than anticipated. However, there is insufficient information on which to base a more precise quantification.

More detailed data and comparisons with 1982-83 and 1992-93 can be found in Section 4.

1 Introduction

1.1 Purpose and methods of the mass flow analysis

The overall purpose of this mass flow analysis is to update our present knowledge of the use, consumption and dispersal of mercury in Denmark.

The circulation of mercury in Denmark is relatively well-described, as mass flow analyses have been carried out for the years 1982-83 (Hansen, 1985) and 1992-93 (Maag et al., 1996). These analyses contain detailed information on all of the major areas where mercury is used. There has been a significant drop in the consumption of mercury since 1992-93. The latest statutory order on mercury prohibiting the sale of mercury with a few specific exceptions entered into force in 1998.

Methods
This mass flow analysis has been executed in conformity with the guidelines for mass flow analyses listed in the Danish EPA's revised paradigm for this type of analysis (Hansen & Lassen, 2000), as mass flow analyses are conducted at the level designated "detailed level" in the paradigm.

This mass flow analysis was implemented by combining information obtained from Statistics Denmark, trade organisations, the Danish Product Register, literature studies and by personally approaching a large number of manufacturers, importers, know-how centres and public institutions.

References to the data sources are generally given in the case of information obtained from literature studies, statistics, know-how centres, and public institutions. Information from enterprises, dealers and importers has generally been used without reference to the source thereof, as this has often been desired by the sources themselves, although Appendix 2 contains a list of the enterprises to which application was made in conjunction with this mass flow analysis.

Almost all quantitative information in this form of analysis has an inherent uncertainty, which is not susceptible to assessment with conventional statistical methods. The "confidence" intervals given should be considered to be intervals, within which the authors have subjectively assessed that there is a 90% probability of the correct value being found. This means that there is a certain probability that the correct values are outside the stated intervals and that, in the case of individual groups of goods or emission values, it is possible that the correct value is far from the interval. However, summation of the intervals means that the probability of the correct sum being found within the resulting interval increases in proportion to the number of quantities summated.

The intentional use of mercury has dropped considerably over the last decades. This means that, with the exception of a couple of major specific uses, the data on the use and consumption of mercury is very scattered. Thus, as use decreases, it becomes increasingly difficult to find quantity data, and the uncertainty of the quantity calculations used in this type of mass flow analysis increases.

1.2 Introduction to mercury

Mercury is the only pure metal that is a liquid at room temperature. It has a mirror-like surface, as can be seen, e.g., from old thermometers and barometers. Due in particular to the danger it presents to the environment, the use of mercury in Denmark has been reduced considerably over the last two decades. In fact it is now probable that many of the younger generation have not seen products that obviously contain mercury - with the possible exception of the classical U-pipe pressure gauge or in the materials collections of school physics laboratories.

The chemical symbol for mercury is Hg and its atomic weight is 200.6 u. Mercury's melting point is -39°C, which is the lowest of all pure metals. Its boiling point is also low, 357°C, which means that there is considerable evaporation from mercury at room temperature, should it be left exposed, e.g., a lost drop from a broken thermometer, concealed in a carpet. This also means that mercury vapour can be carried thousands of kilometres from the point of emission, and that a low concentration of mercury vapour is continuously present in the atmosphere. As it is the only liquid metal, and because of a number of other technically advantageous properties, man has used mercury for thousands of years, in a great variety of applications.

Mercury can be found in many minerals, although cinnabar (mercury sulphide) is in practice the only ore from which mercury is extracted as the principal product. As the use of mercury decreases, especially in the Western world, but also globally, only a few mines dedicated to the extraction of mercury are in operation. However, mercury is also widely extracted together with other metals, particularly zinc, and gold, and these sources constitute an ever greater proportion of the supply, as the dedicated mercury mines are being closed. Certain countries are considering (and perhaps already implementing to some extent) the deposition in landfills of this by-product, rather than marketing it on a rapidly declining market.

At the same time, recycled mercury constitutes an increasing share of the market. In particular, used mercury from disused or converted chloro-alkali manufacturing plants is a primary contributor, although there are also smaller contributions from used and collected products. Because of plans to phase out the use of mercury in chloro-alkali manufacturing in many European countries (parties to the OSPAR and HELCOM Conventions), there is international concern that the market will become swamped with mercury, with the concomitant risk of increasing use in countries where less strict regulations apply to the use of mercury. Because of the hemispheric and global atmospheric transportation of mercury, such use in other countries would locally and globally contribute to the environmental impact caused by mercury - also in such countries as Denmark, where a great effort has been made to reduce such impacts.

Mercury can cause various types of serious harm to human health and the environment. Perhaps most serious is harm to the human nervous system in the embryo phase which, even under quite ordinary conditions, is considered to cause retarded learning and development in children. Studies in the Faeroe Islands have shown that such damage probably occurs at even very low concentrations of mercury. Recent studies in the USA have shown that as many as 8% of a representative group of women had concentrations of mercury in their blood, at levels that cannot be precluded from causing such injuries in the children they bear. There is no immediate basis for believing the situation to be significantly different in Denmark. As far as can be ascertained, however, there are no up-to-date studies of this in Denmark (UNEP, 2002).

Table 1.1 below reviews the development of the known global production of newly extracted mercury. In addition there is, as mentioned above, the sale of recycled mercury, probably together with a certain amount of unrecorded, newly extracted mercury.

Table 1.1
Recorded annual global production of newly extracted mercury (tonnes; source: Jasinski, 1994); Reese, (1997; 1999); and Hylander & Meili (2002), all as quoted by UNEP (2002).

Period	1981-1985	1986-1989	1990-1995	1996	1997	1998	1999	2000
Recorded annual global production of newly extracted mercury (tonnes)	5500-7100	4900-6700	3300-6100	2600-2800	2500-2900	2000-2800	2100 2200	1800

There are no satisfactory estimates of the distribution by use of global mercury consumption. At the global level, chloro-alkali manufacturing, gold extraction on a smaller scale, test and monitoring equipment and dental fillings are included among the major single applications. For the sake of comparison to the Danish figures presented in this mass flow analysis, Table 1.2 shows the estimated distribution of mercury use in the USA for 1990 and 1996.

Table 1.2
Recorded consumption of mercury in the USA in 1990 and 1996 (tonnes/year; source: Jasinski (1994) and Sznopek & Goonan (2000); both as reviewed in UNEP, 2002).

Use	1990	1996
Dental fillings	44	31
Laboratory applications	32	20
Monitoring equipment	108	41
Switches, contacts, relays and elec. cable eqt.	70	49
Light sources	33	11
Paint	14	0
Batteries	105	0
Chloro-alkali production	247	136
Miscellaneous	58	84
Total	711	372

People ingest mercury from a number of different sources. The greatest quantity is normally ingested from the mercury-silver amalgam used in dental fillings, but the present body of knowledge indicates that the most disturbing source is fish and other food products associated with the aquatic environment. This is because the mercury here occurs mainly in the form of methyl mercury, which due to its ease of absorption, and accumulation in the body has an actual toxicity greater than (elementary) metallic mercury.

Metallic mercury is converted naturally by micro-organisms in the environment to methyl mercury, which bioaccumulates rapidly in the food chain. Thus, the greatest concentrations are to be found in large, old, predatory fish, animals, and birds high in the food chain. The presence of fish with a mercury content that can be harmful through high ingestion has been demonstrated in most places in the world. Mercury also occurs naturally in the environment. It is extremely difficult to assess precisely the relationship between man-made and natural sources, but the body of knowledge

indicates that man-made sources have the greatest impact. Over the past several years, man-made sources seem to have diminished globally, however this is presumably mainly the case in the Western world.

For the above reasons these years (2001, 2002 and 2003) have therefore witnessed renewed deliberations on the need for expanded international collaboration on reducing the release of mercury (see the discussion of this process on the mercury pages of the UNEP Chemicals web site, www.chem.unep.ch/mercury).

The sale and purchase of toxic substances, such as mercury and its compounds, requires a special licence, which is administered by the National Working Environment Authority (purchase for own commercial use), the Danish EPA's Chemical Inspection Service (sale/purchase for reselling) and the police (purchases for own use e.g., by private purchasers and schools).

2 Uses in Denmark

2.1 Raw materials and semi-manufactured goods

Imports, exports and manufacturing of raw materials and semi-manufactured goods containing metallic mercury or mercury compounds, as recorded by Statistics Denmark for the years 1996-2001, are shown in Table 2.1.

Table 2.1
Supply information from Statistics Denmark for metallic mercury and mercury compounds for the years 1996-2001 (tonnes). *1

		1996	1997	1998	1999	2000	2001
Metallic mercury	imported	1.2	1.4	0.9	1.1	0.6	1.3
	exported	0	4.4	0.4	0,2	0.1	0.9
Sulphates of	imported	34.9	31.7	0.8	55.4	66.5	0
mercury and lead	exported	0	0	0	4.4	0	0
Nitrates of mercury	imported	0	0	0	0	0.1	0
and copper	exported	0	0	0	0	0	0
Precious metal	imported	67	36	0	0	68	3
amalgams	exported	0	0	0	2	6	12

Notes:
*1 The quantities shown in the table have been obtained from Statistics Denmark and are given in tonnes. The relationship between the quantities shown in the table and the position numbers of the goods statistics are as follows:
Metallic mercury: position numbers 2805.40.10 and 2805.40.90;
Sulphates of mercury: position number 2833.29.70;
Nitrates of mercury: position number 2834.29.30;
Mercury amalgams: position number 2843.90.10.

Of the recorded imports/exports, the following should be noted:

Manufacturing
In 2001, as was also the case in the previous report of 1996, no manufacturing of the above chemical compounds was recorded.

Metallic mercury
Imports of metallic mercury are used in the applications shown in Table 2.2, which is based on information obtained during this mass flow analysis. The difference between the recorded consumption during 2001, of about 600 kg, and total imports, of 1,300 kg, can be attributed to the re-exportation of part of the imported mercury and to stock fluctuations. Thus, it has not been possible to locate 900 kg of pure mercury destined for export through the recycling industry.

Sulphates and nitrates of mercury
In both cases, the information available from Statistics Denmark covers compounds of mercury and lead. As stated in Section 2.3.2, the consumption of mercury-containing compounds is marginal in Denmark today, i.e., 30-60 kg mercury-containing

compounds, which corresponds to 20-40 kg of mercury/year. Thus, the remaining imports must be assumed to apply to lead compounds.

Amalgams
Denmark imports/exports a certain quantity of amalgams. According to Statistics Denmark, 2001 witnessed a net export of 9 tonnes of precious metal amalgams.

It has not been possible to identify the listed quantities of imports/exports of precious metal amalgams. Whether or not capsules of mercury and amalgam powder for dental amalgams are recorded by Statistics Denmark remains unknown. Such capsules are not manufactured in Denmark. Therefore it is not possible to explain the large net export for the year 2001.

Table 2.2
Metallic mercury consumed in manufacturing, etc., in Denmark in 1992, 1993 and 2001.

Use	1992 (kg)	1993 (kg)	2001 (kg)
Electrolysis	3,000	2,000	0
Mercury for use in dental amalgams	1,500	1,500	550-650 1)
Manufacture of thermometers	400	400	0
Manufacture of batteries	200-300	200-300	0-9
Monitoring equipment, laboratories	550-650	250-350	10-30
Total	5,800	4,500	560-690

1) The quantity listed for 2001 covers 50% of dentists' consumption of mercury purchased in the form of pure mercury.

2.2 Use of mercury as a metal

2.2.1 Dental fillings

Description
Dental amalgam is a mixture of mercury, silver, copper and tin, of which mercury constitutes between 44 and 51% by weight, although typically 48-49% (Munksgaard, 2001). An average mercury content of 48% has been assumed in this report. Silver constitutes the greater part of the remainder, whereas copper and tin are only included in smaller quantities.

Amalgam is supplied to dentists, partly in the form of pure mercury which is mixed on the dentists' premises with the amalgam powder that contains the other constituents, and partly as individual capsules containing the mercury and amalgam powder, separated by a thin membrane, which ruptures when shaken in special shaker machines. The use of these capsules is considered to result in less waste in the form of excess amalgam, than the method of weighing at the individual clinic. Capsules account for about half of the Danish consumption of amalgam.

Consumption in Denmark
Consultation with the four Danish dealers in mercury for dental amalgam revealed a total Danish consumption of mercury in amalgam of about 1,200 kg in 2001.

Roughly the same result can be obtained from based on performed on the number of fillings. For dentists in private practices, the annual consumption of mercury in amalgam for dental fillings can be calculated from their reports to the National Health Service, of the numbers of amalgam fillings performed. In addition to this, there is municipal dental care (i.e., the school dental service), which is not within the scope of the reports sent to the National Health Service.

Private dentists
Table 2.3 shows the number of amalgam fillings performed in private dental practices in Denmark and reported to the National Health Service for the years 2000 and 2001. The reported number of fillings for all years between 1994 and 2001 can be found in Appendix 1. The previous mass flow analysis (Maag et al., 1996) has corresponding data for the years 1980-1983.

In the reports to the National Health Service - and in Table 2.3 - the size of the fillings are shown as "a," "b" and "c," depending on the number of tooth surfaces that were covered with the filling material. Based on detailed investigations, the amalgam consumed (including waste) for performing "a"-, "b"- and "c"-type fillings has been estimated as follows (Maag et al., 1996; Munksgaard, 2001) (the numbers correspond to those of the previous mass flow analysis):

"a" filling (one surface):	1.2 g
"b" filling (two surfaces):	1.8 g
"c" filling (three surfaces):	2.4 g

Table 2.3
The National Health Service's accounting of the number of amalgam fillings performed, distributed by filling size "a," "b" and "c," for the years 2000 and 2001. This account only covers fillings performed in private dental practices 1).

Year		2000		2001	
		Number of fillings	Mercury consumption	Number of fillings	Mercury consump.
Size	"a"	300,567	170 kg	274,272	160 kg
	"b"	620,838	540 kg	576,289	500 kg
	"c"	279,000	320 kg	259,627	300 kg
Total		1,200,405	1030 kg	1,110,188	960 kg

1) The figures reported to the National Health Service are considered to be reliable and precise. The numbers shown in the table include temporary amalgam fillings (so-called "gradual excavation"), which the National Health Service accounted separately for the years 1999-2001.

Public dental care
In January 2002 the National Health Service estimated that 6,000 mercury amalgam fillings are performed annually on milk teeth (Nielsen, 2002). If an average of 0.4 g mercury/filling is assumed, as in the previous report (Maag et al., 1996), 2.4 kg of mercury were used in fillings in milk teeth.

In addition to this amalgam is used in public dental care for the permanent teeth of youths. Each child receives an average of 0.8 fillings/year. On the assumption that 20% are amalgam fillings (type "a"), the total mercury consumption in municipal dental care - about 1m youths - can be estimated at about 100 kg of mercury/year (Holst, 2002).

Total consumption
The total mercury consumption for dental fillings in Denmark in 2001 can, thus, be estimated at about 1,200 kg/year. It is realistic - based on the authors' assessment - to calculate with an uncertainty of ±100 kg. This relatively low uncertainty is due to the fact that the information given by all dealers in amalgam agrees well with the consumption calculated from the number of fillings.

Development trends
The consumption of amalgam for dental fillings has dropped somewhat over the course of the past 20 years. Thus, the total consumption in 1982-83 was calculated as 3,100 kg of mercury and for 1992-93, as 1,800 kg of mercury. The number of amalgam fillings reported to the National Health Service has dropped from 2.7m in 1982 to 1.8m in 1992 and 1.1m in 2001. This reduced consumption is thought in part to be due to improved dental hygiene in the population, and in part to be due to the increased use of alternative filling materials. One significant factor here is probably the prohibition against using mercury in teeth other than the molars and premolars, where fillings are subject to wear (Statutory Order No. 692 of 22 September, 1998 on prohibition of sale and expert mercury and mercury-containing products).

Subsequent fate of amalgam
This report estimates that about 60% of dental mercury ends in teeth. This corresponds to the estimate of the previous mass flow analysis, and it corresponds to about 1 g amalgam/tooth (Munksgaard, 2002), i.e., that between 660 and 780 kg of mercury/year ends in finished dental fillings.

The rest of this consumption sector is collected as excess amalgam or is taken by saliva ejectors together with the mercury from old, excavated fillings.

Excavation of old fillings
The average life-cycle of amalgam fillings is estimated at between 7 and 20 years (Munksgaard, 2002). Thus fillings removed for replacement today were on the average performed in approximately 1988. In 1992-93, dental mercury consumption was about 1,800 kg/year (Maag et al., 1996), whereas the figure in 1982-83 was about 3,100 kg/year (Hansen, 1985). On the expectation that about 50% of this mercury was filled in teeth, about 1,100-1,300 kg of mercury would have been used for dental fillings performed in 1988. Part of this mercury will be excavated with old fillings, part will accompany extracted or lost teeth, and the remainder will be in the teeth of the deceased, who are buried or cremated.

For 2001, the excavation of old fillings is estimated to account for 660-1,100 kg of mercury. This follows from the following figures (from the previous mass flow analysis):

Present in old fillings	1,100-1,300	kg
Present in extracted or lost teeth	120-180	kg (see below)
Present in the teeth of the deceased	about 240	kg (see below)
Present in fillings to be replaced	680-940	kg

Due to the great attention to the effects of mercury in teeth, there is reason to believe that some people have the amalgam in their fillings replaced with other materials, before the amalgam fillings are worn out. This means that the excavated quantity could exceed the estimated 940 kg. It is difficult to quantify this precisely, but for the purpose of this report, a maximum of 1,100 kg of excavated mercury has been assumed. For

this reason, the excavation of old fillings is considered to represent 680-1,100 kg of mercury/year.

Collection of mercury from dental cuspidors
All dental chairs are equipped with a strainer that captures large particles. The strainer is manually emptied from one to five times a week (Marker, 2002; Lindstrøm, 2002). Its content - or at least the visible fragments of amalgam - are separated as mercury-containing waste. The residue is disposed of as ordinary waste or flushed down the sink where the sorting was carried out.

Amalgam filters
After the strainer, the cuspidor system may be equipped with an amalgam filter, which collects 90-99.9% (Bindslev, 1999; Marker, 2002) of the mercury in the wastewater. Most of Denmark's local councils have issued regulations on the use of amalgam separators that have a maximum discharge, e.g., of 5 g mercury/year. The Århus School of Dentistry has conducted questionnaire surveys in all of Denmark's local councils (Bindslev, 2002). It was apparent from the 239 responses that such regulations had not been issued by 27% of the local councils.

The largest filter manufacturer collects most of its filters itself. The filters are disassembled in Denmark and the content of the filters is sent to The Netherlands for processing. The filters are cleaned and reused. In Denmark the cleansing process occurs in a closed system, with recirculation of the water and with filters in the ventilation exhaust. The efficacy of the air filters has not been measured and they are so new that they have not yet been replaced. Based on our knowledge of the number of amalgam filters processed, the total amount of mercury released to air and water is considered to be between 1 and 5 kg.

Another filter manufacturer also collects used filters and part of the mercury-containing waste from dental clinics. This is sent to Sweden where the filters are cleaned for reuse and the mercury is processed. About 30% of the remaining mercury-containing waste from dental clinics is considered to be collected together with the filters and exported.

The last fraction of the filters are sealed when they are replaced and are left at the clinic. Depending on the local council's regulations, they are disposed of together with the clinic's other mercury-containing waste.

One collector of amalgam filters states that, when collected, each filter typically contains 250 g mercury. Although this figure is lower than the assessment of the previous mass flow analysis, it has been verified by the Swedish purchaser. Consultation with the filter manufacturers reveals that 2,900-3,800 filters are sold annually in Denmark. It must be assumed that a corresponding number is collected, i.e., that 690-950 kg of mercury is collected annually from amalgam filters. Of this, an estimated 480-575 kg is exported to The Netherlands and Sweden where it is processed. The remainder is collected and delivered to Kommunekemi.

Discharges to wastewater
Assuming that amalgam filters are 98% effective, 15-20 kg of mercury is discharged to wastewater from dental clinics equipped with amalgam filters. In addition are the discharges from dental clinics that lack such filters, which can be estimated at about 175-240 kg. Thus, the total discharge from dental clinics to wastewater can be calculated as 190-260 kg of mercury/year. Here, it has been assumed that 80% of Danish dental clinics are equipped with amalgam filters and that the total discharge

from the remaining 20% of clinics is in proportion thereto. About 27% of Danish local councils lack regulations on filters. This circumstance is also assumed to apply to dental clinics, but as many dental clinics in these areas nevertheless are considered to have filters, 20% of clinics are thought to lack filters. However, there is significant uncertainty associated with this figure.

For the sake of comparison, an investigation of a limited number of clinics, conducted on a single day in Århus, revealed a discharge of 65-842 mg of mercury/dentist (corresponding to 7-185 g of mercury/year) into the municipal sewers from clinics without filters. At clinics with amalgam filters the discharge was 12-99 mg of mercury/dentist (2.6-22 g of mercury/year) (Arenholt-Bindslev, 1996). If this is assumed to be representative of 20% and 80%, respectively, of all approximately 5,000 dentists in Denmark, it corresponds to a discharge of 20-270 kg of mercury/year. This corresponds very well - considering the paucity of data - to the above estimate.

To summarise, the following assessment is made of discharges to wastewater from dental clinics:

A discharge of 20 kg is based on a limited number of measurements and must be assumed on the basis of other available data to be too low, whereas a discharge of 50 kg of mercury/year is not unrealistic. On the other hand, a possible total discharge of as much as 250 kg/year cannot be dismissed. The discharge to wastewater from dental clinics is therefore assessed as 50-250 kg of mercury/year.

Amalgam in extracted and lost teeth
By far the greater part of the teeth lost by adults are extracted by their dentists, whereas only a small number are actually lost. This report considers the number of teeth lost by adults to be insignificant.

According to National Health Service data for the number of teeth extracted annually, 354,519 were extracted in private practice (i.e., teeth that count as adult teeth, see Appendix 1). It must be considered likely that a significant number - perhaps the greater part - of all these teeth contained amalgam fillings. If, as in the previous mass flow analysis (Maag et al., 1996), it is assumed that the average weight of these fillings is 1 g (amalgam), they account for an annual 100-150 kg of mercury.

The quantity of mercury lost and extracted during the years children are treated under the school dental service must also be added to the above figure. However, as the use of mercury in dental fillings has been prohibited since 1 January 1995, with the exception of fillings in molars and premolars, where they are subject to heavy wear, many clinics have stopped using mercury in milk teeth. As most of the teeth extracted and lost in these age groups are milk teeth (mercury consumption for new fillings in milk teeth is about 2.4 kg/year), and only a limited number is estimated to consist of permanent teeth (mercury consumption for new fillings in permanent teeth is about 100 kg/year), the quantity of mercury from teeth lost or extracted under the school dental service is estimated at 20-30 kg/year. In the previous report, when the use of mercury in milk teeth was more widespread, this was estimated at about 250 kg/year.

Thus, it can be estimated that a total of 120-180 kg of mercury/year is disposed of together with extracted and lost teeth. Of this, it is estimated that 20-30%, i.e., about 20-50 kg of mercury, enters the waste stream (refuse), whereas the remainder, 70-160 kg, will be passed to Danish schools of dentistry (which collect teeth for educational

purposes), to Kommunekemi or, together with amalgam filters, to the filter manufacturers.

Amalgam in the teeth of the deceased
The previous mass flow analysis calculated with an average of 2 g of mercury in the teeth of the deceased in the Western world. Compared to earlier times, far more people retain their teeth until they die. According to Marker (2002), it is reasonable to calculate with 4 g mercury/deceased.

About 58,000 people died during the course of 2001, of which about 41,000 were cremated and 17,000 were buried (Hansen, 2002). This means that about 170 kg of mercury is passed to Danish crematoria, while about 70 kg is buried in cemeteries. As the crematoria are not equipped with flue gas cleaning equipment capable of capturing mercury vapour, it is to be expected that all of the mercury passed to the crematoria is emitted to the atmosphere.

Mercury-containing waste
Mercury-containing waste consists of excess amalgam from strainers and, possibly, extracted teeth containing amalgam fillings. Typically, this waste is stored by dentists in a water-filled container, until it is delivered to the local receiving station for chemical waste. Individual collectors of filters also collect mercury-containing waste, although there are no longer any actual collectors of excess amalgam or mercury-containing waste (Due, 2002; Metaligen, 2002; Petersen, 2002). The reason for this is stated as being the small quantities, low price, and the complicated procedures that apply when transporting hazardous waste. These factors make it extremely difficult to estimate quantities. Based on the sold and excavated quantities of dental mercury and the quantity in wastewater and amalgam filters, the total quantity of mercury in this waste fraction is estimated at 120-680 kg/year.

Employees at dental clinic are considered to be aware that mercury-containing waste must not be disposed of in refuse and it is assumed that the main part of mercury-containing waste (calculated as 60-80%) is collected separately, whereas the remainder is assumed to enter the refuse stream. In other words, about 50-140 kg of dental mercury enters the refuse stream, whereas 70-540 kg is collected.

About 30% of collected mercury-containing waste is exported together with collected filters destined for export. This corresponds to 20-160 kg of mercury/year. The remainder is sent to Kommunekemi. The mercury balance for dentists is shown in Fig. 2.1. It should be noted that no attempt has been made to estimate the emission of mercury vapour to air from dental clinics. Neither has any attempt been made to quantify the amount of mercury which, together with cotton pledgets and similar low-contamination waste from dental clinics, can be conceived of as entering the refuse stream. There is no information to give reason to believe that these quantities of mercury are of any significance.

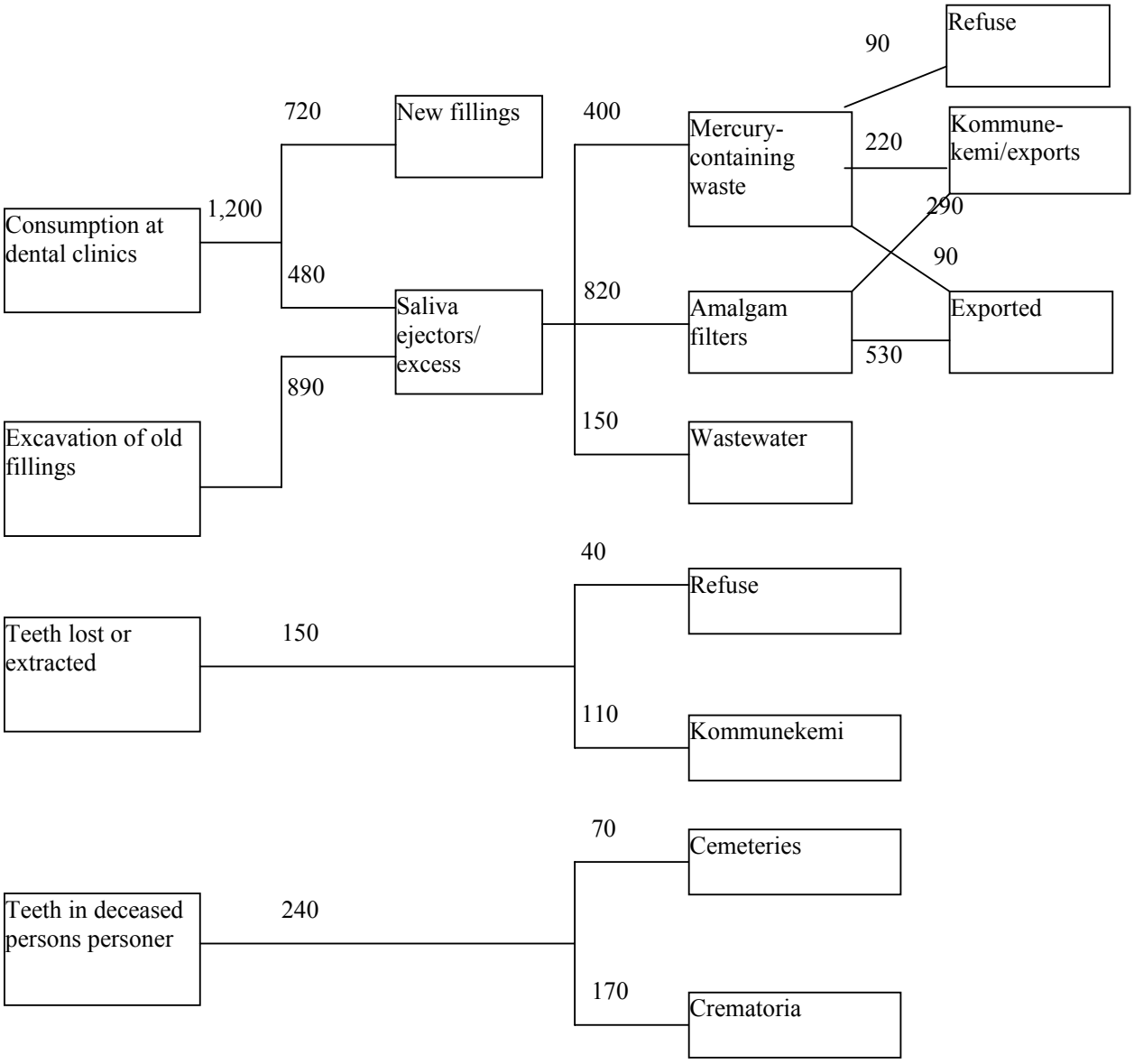

Refuse
90
720
New fillings
400
Mercury-containing waste
220
Kommune-kemi/exports
1,200
Consumption at dental clinics
290
90
480
820
Saliva ejectors/ excess
Amalgam filters
Exported
530
890
150
Wastewater
Excavation of old fillings
40
Refuse
Teeth lost or extracted
150
110
Kommunekemi
70
Cemeteries
Teeth in deceased persons personer
240
170
Crematoria

Fig. 2.1
Estimated circulation of mercury within Danish dental care in 2001 (calculated as average, rounded numbers, kg of mercury)

2.2.2 Light sources

Most electric light sources of the discharge type contain a small quantity of mercury. Discharge light sources function through the application of a high voltage field across a gas, normally mercury vapour, whereon the gas emits light. For instance, ordinary fluorescent tubes function on this principle. Inside fluorescent tubes, the emitted light strikes the fluorescent powder coating on the inside of the tube. The constituent substances of the fluorescent powder then emit light in the desired colours. Fluorescent powder consists primarily of chemical compounds of the elements known as "rare earths".

Table 2.4 shows the numerically most important light sources that contain mercury. For each type and for various manufacturing years, the table also lists the quantity of mercury/light source

Table 2.4
The numerically most important light sources containing mercury and the mercury content of each type.

Light source	Mercury content (mg/item) 1)	Primary use
Fluorescent tubes	30-40 mg/tube (1993) 15 mg/tube (1997) 10 mg/tube (today)	Indoor lighting
Energy saver lamps (compact tubes)	5-15 mg/lamp (1992, Maag et al., 1996) 2) 5 mg/lamp (1993, 1997, today)	Indoor and outdoor lighting
Mercury vapour lamps	75 mg/lamp (1993) 39 mg/lamp (1997) 30 mg/lamp (today)	Outdoor lighting
High-pressure sodium vapour lamps	20 mg/lamp (1993) 25 mg/lamp (1997) 39 mg/lamp (today)	Outdoor lighting and in shops
Metal-halide lamps	60 mg/lamp (1993) 30 mg/lamp (1997) 25 mg/lamp (today)	Private and offices
UV lamps	25 mg/lamp (Maag et al., 1996)	Solaria

1) Source: Floyd et al., 2002. The mercury quantities for the individual years have been interpolated from the information received.
2) The previous mass flow analysis lists 5-15 mg of mercury/tube. This is based on information given by manufacturers, waste collectors, and various reports.

Mercury is also used in the following light sources, which are not included in Table 2.4:

- super-high-pressure lamps for photographic purposes;

- mercury vapour lamps for chemical analyses (atom absorption) - so-called "quartz lamps"
- UV sterilisation lamps
- LCD screens for computers and televisions
- tubes in advertising signs (see below).

As sales of these light sources are small, their mercury content makes only a marginal contribution to the total consumption of mercury.

Manufacturing in Denmark
Fluorescent tubes for advertising are manufactured and repaired in Denmark. The consumption of other types of light source depends solely on imports.

Consumption in Denmark
Table 2.5 shows the consumption (thousands of lamps) during the period 1997-2001. The mercury consumption of the same lamps in Denmark is estimated in Table 2.6.

Table 2.5
Consumption of mercury-containing light sources during the years 1997-2001 (lamps x 1,000). 1)

Light source	1997	1998	1999	2000	2001
Fluorescent tubes	6,100	2,739	5,498	4,557	4,228
Energy saver lamps (compact tubes)	4,403	4,653	3,741	4,562	5,688
Mercury vapour lamps	370	135	221	139	107
Sodium vapour lamps	222	72	211	156	99
Metal-halide lamps	26	63	75	63	120
Other discharge lamps	392	228	291	589	759
UV lamps	420	431	441	324	263

1) Information on the numbers is based on information from Statistics Denmark. Discharge lamps consist, e.g., of mercury vapour lamps, sodium vapour lamps and metal-halide lamps.

Table 2.6
Consumption of mercury in light sources during the years 1997-2001 (kg of mercury). 1)

Light source	1997	1998	1999	2000	2001
Fluorescent tubes	92	38	71	55	42
Energy saver lamps (compact tubes)	22	23	19	23	28
Mercury vapour lamps	14	5	8	5	3
Sodium vapour lamps	6	2	6	4	3
Metal-halide lamps	1	2	2	2	3
Other discharge lamps	12	6	8	15	19
UV lamps	11	11	11	8	7
Total (approximate)	157	87	125	111	105

1) Based on Tables 2.4 and 2.5.

As can be seen from Table 2.6, the total consumption of the lamp types shown in the table for 2001 is estimated at 105 kg of mercury. For this report, it is realistic to calculate with an uncertainty of ±50 kg, based on the authors' assessment.

Specially formed advertising tubes
According to information provided by a number of manufacturers of advertising tubes, consumption for tubes today can be roughly estimated at 1-5 kg of mercury/year. In the previous report for 1992-93 mercury consumption for advertising tubes was listed as 15 kg/year. This market is declining. The mercury is added manually using a thin glass pipette. One small drop is added to each fluorescent tube. Today, some advertising signs are manufactured with diodes and optical fibre. These technologies are advancing rapidly.

LCD screens for computers and televisions
Flat screens, so-called "LCD screens," for computers - also including screens for portable computers - contain mercury-containing light sources (LCD: liquid crystal display). The same applies to LCD screens for televisions, although they are still only assumed to have very limited penetration in Denmark.

According to Floyd et al., 2002, screens for portable computers typically contain 2-4 lamps/screen, depending on the size of the screen. A 15" screen will typically contain four lamps, whereas larger screens can contain 6, 8 or more lamps. In 2001, the typical mercury content of each lamp was between 2.5 and 3.5 mg/lamp (the present requirements for affixing the EU ecolabel to LCD screens state that the mercury content must not exceed 3 mg/lamp).

Sales of portable computers in Denmark amounted to about 75,000 in 1997 (IDC, 1999).

Sales of flat screens for computers can be estimated from the total use of stationary personal computers, i.e., about 500,000 (figure for 1997, IDC, 1999), the assumption that approximately one screen is sold for each personal computer and an assessment of the distribution of new sales of screens over conventional CRT screens and flat screens. One large retail chain estimated that, in 2001, this distribution was about 75% CRT screens and 25% flat screens, but that the distribution shifted very rapidly during 2002, so that the ratio was estimated at 60/40 at the end of the year. This shift towards flat screens is expected to continue.

Sales of televisions with LCD screens are, as mentioned above, very limited (due to the extremely high prices), and no attempt has been made to quantify the mercury consumption of these screens.

Thus, the consumption of mercury for flat screens can be estimated as follows:

portable computers: 75,000 pieces * (2 to 4 lamps) * 0.000003 kg/lamp: 0.5-0.9 kg of mercury;

flat screens for stationary personal computers: 0.25 * 500.000 pieces * (4 to 6 lamps) * 0.000003 kg/lamp: 1.5-2.3 kg of mercury.

As sales of both types of product can have been a little higher in 2001 than in 1997, and as uncertainty is also associated with the numbers of lamps and the mercury content of the lamps, the total consumption of mercury for flat screens in 2001 is estimated at 2-5 kg.

Light sources in vehicles
A major manufacturer and dealer reports that mercury-containing lamps are seldom used in vehicles. A qualified estimate is 1% of vehicle sales and a mercury content of a few milligrams/lamp. About 115,000 cars were sold in Denmark in 2001 (Statistics Denmark, 2002). The assumption that 1% of the cars sold in 2001 were equipped with mercury discharge lamps yields 1,150 cars.

Each lamp contains between 5 and 10 mg of mercury (Ecology Centre, 2001). If we assume six lamps/vehicle, we obtain a total mercury consumption of between 35 and 70 g. We should also mention that mercury-containing lamps are being used to an increasing extent, even in relatively inexpensive vehicles (Ecology Centre, 2001).

Discharge lamps used for back-lighting displays on the instrument panel also contain mercury (in similarity to LCD screens), and substitution is not possible today (Lohse, 2001). The quantity of mercury in the individual units is not known and is highly variable. An American study states that 1.2 mg is used for a navigation system and less than 40 mg, for a speedometer. The same study also shows the vehicle models of the year 2000 that are equipped with discharge lamps. The list is probably not exhaustive, but it includes a number of vehicle manufacturers that are known on the Danish market. This is, however, a question of luxury vehicles. Bearing in mind this consideration, we shall assume that 1% of the vehicles sold in 2001 were equipped with discharge lamps, and if we also assume that each vehicle contains 40 mg of mercury, the total consumption is 46g.

Total consumption
The total consumption of mercury in light sources is, thus, estimated at 60-170 kg of mercury/year, of which 100 ±50 kg is for the most common types (see Table 2.6), 1-5 kg for specially-formed advertising tubes, 2-5 kg for LCD screens (flat screens) and less than 1 kg for backlit display panels in vehicles.

Development trends
The consumption of mercury for light sources has dropped since the previous mass flow analysis, in which it was assessed as 170 kg in 1992. The drop to about 115 kg (the average of 60-170 kg) for 2001 principally occurred because the mercury content/light source is lower today. The consumption of linear fluorescent tubes dropped by almost 2m from 1999 to 2001. The consumption for 1988-1992 was 5-6m tubes. On the other hand, the consumption of energy saver lamps increased, from 0.6m in 1998, to 5.7m in 2001.

Losses in manufacturing
As has already been mentioned, the consumption of mercury for Danish manufacturing of light sources (advertising tubes) is very small. Manufacturing losses are considered to be insignificant.

Losses in conjunction with disposal
The quantity of mercury disposed of with light sources in 2001 can be estimated at about 140 kg (uncertainty interval: ±40 kg). This estimate makes allowance for the fact that most mercury-containing light sources probably have a life-cycle of 8-10 years, and that mercury consumption for light sources for 1992 was assessed as being about 170 kg (Maag et al., 1996). The previous mass flow analysis calculated with a life-cycle of "3-4 years, or more." In this report, the life-cycle has been estimated at 8-10 years as this is the life-cycle usually applied for fluorescent tubes, energy saver lamps and vapour lamps.

Depending in part on local waste-collection schemes, burned-out energy saver lamps and other small light sources are expected mainly to be collected with refuse, whereas other types of light source are collected separately, normally through schemes for bulky waste.

There is a recovery plant in Denmark that processes straight fluorescent tubes. In this plant the metal ends are cut off and sent to smelting works, the mercury-containing powder is blown out and returned to the original manufacturers of fluorescent tubes for reuse. The glass is cleaned and sent to glassworks, so that it can be reused in new light sources. Thus, more than 98% of these fluorescent tubes are reclaimed. The entire process occurs in a closed system, with activated charcoal filters on the output streams. This plant processes about 2.6m straight fluorescent tubes a year. About 70% of the fluorescent powder from the plant can immediately be reused in manufacturing new tubes. Manufacturing takes place abroad. The remainder (about 30%) is sent to Belgium for processing (distillation). 2.6m fluorescent tubes, each containing about 15 mg of mercury, corresponds to 40 kg of mercury. In addition, there is the exporting of about 500,000 straight tubes from other collectors, as well as broken tubes and other mercury-containing light sources. Based on information on consumption of the different types of light source, the author considers this to correspond to about 10 kg of mercury.

According to information provided by Kommunekemi, 156,258 kg of mercury-containing light sources were received in 2001. Fluorescent tubes weigh 50-300 g each and contain about 15 mg of mercury/tube, energy saver lamps weigh 40-100 g and contain 5-10 mg of mercury, while vapour lamps weigh 30-200 g each and contain 25-39 mg of mercury. Assuming that the light sources weigh an average of 100-200 g and contain 15 mg of mercury each, 10-20 kg of mercury were delivered with light sources to Kommunekemi in 2001. Light sources are deposited at Kommunekemi's site with a view to subsequent processing abroad (Naamansen, 2003). In this report, this quantity has been counted with exports.

Altogether, it is estimated that 60-80 kg of mercury (10-20 kg of which is delivered to Kommunekemi) is collected and exported, whereas 20-120 kg of mercury ends in refuse.

Some of the light sources are broken during handling - especially during the collection and sorting of the tubes. This occurs under normal, unfiltered, ventilation conditions. When the light sources are crushed, mercury is emitted to the air. Although there are no figures for the quantity of broken light sources, it

does not seem unreasonable to assume that 1-5 of every 100 light sources are broken during the time from when they enter the country until they are incinerated or re-exported. 1-5% of the potential of 100-180 kg of mercury corresponds to 1-9 kg, i.e., the discharge to air resulting from broken light sources can be roughly estimated at 1-9 kg of mercury/year.

Disposal summary:

Collection potential:	100-180 kg of mercury/year
Exported:	60-80 kg of mercury/year
Refuse:	20-120 kg of mercury/year
Emitted to air:	1-9 kg of mercury/year.

2.2.3 Electrical switches, contacts and relays

Mercury-containing electrical switches, contacts, and relays have been used in many different situations over the years. Table 2.7 shows the uses of mercury-containing switches, contacts and relays for which, on the basis of available information, application is found, has been found, or could have been found in Denmark within a reasonable period.

Table 2.7
Use of mercury-containing switches, contacts, and relays

Product	Type and function of mercury-containing component	Use	Annual mercury consumption, kg/year	Source
Freezers and refrigerators	Switches that light an internal lamp when door opened	Discontinued around 1990	-	(Maag et al., 1996). Not covered in this investigation
Coffee machines and flat irons	Thermal cut-outs/tip-over switches	Discontinued, year unknown	-	(Maag et al., 1996). Not covered in this investigation
Submersible pumps	Level switches with tilt switches for controlling liquid levels	Discontinued around 1996	-	(Friis, 2002)
Cars	Switches to light internal lamp when doors opened	Discontinued around 1980	-	(Maag et al., 1996). Not covered in this investigation
	G-sensors in certain ABS braking systems	Discontinued around 1996	-	(Nyborg, 2002) (Rasmussen, 2002)
	G-sensors in airbag systems	Discontinued at start of 1990s	-	(Maag et al., 1996). Not covered in this investigation
All types of telephone	Switches in certain handsets	Discontinued at end of 1980s	-	(Maag et al., 1996). Not covered in this investigation
	Mercury relays in electronics of telephones	Discontinued at end of 1980s	-	(Maag et al., 1996). Not covered in this investigation
Telephone exchanges	Mercury relays in analogue exchanges	From 1960s. Discontinued during 1990s	-	(Mehlsen, 2003)
Televisions	Relays	Discontinued in 1980s	<2 kg, see text	(Wessel, 2002)
Computing equipment	Reed-relays for data transmission, as well as mechanical relays	No certain information	<5 kg, see text	
Other electronics	Reed-relays	Reed-relays are still in use, but probably only find limited application	<10 kg, see text	(Maag et al., 1996)
	Toggle switches	Toggle switches in other electronic equipment are covered by the prohibitions of the Mercury Statutory Order - no information available on actual use hitherto		
Industrial plant	Rotary switches	Limited use under exemptions	about 2 kg	Exemption (Heron, 2001)
Flashing lights for rail traffic	Toggle switches	Still in use	0.190 kg/year	(Sørensen, 2002)
Remote control of rail traffic	Mercury wetted electrodes	Still used, but only for repairs to existing installations - substituted in new installations	Marginal	Danish National Railway Agency (2003)
Theft alarms for boats, motor cycles, etc.	Function unknown (probably tilt switches)	No information	<5 kg, see text	(Maag et al., 1996) Not covered in this investigation

Temperature and pressure switches	Temperature and pressure control	No certain information	<1 kg, see text	(Maag et al., 1996) Not covered in this investigation
Flashing lights in running shoes	Toggle switches	This application was discontinued in 1995	-	(Maag et al., 1996) (Bech, 2002)
Door bells	Mechanical switches	No information	-	(Maag et al., 1996) Not covered in this investigation

The following review of the main applications is focused on the magnitude of consumption. For a more detailed description of the design and modes of operation of different types of mercury based switches, contacts and relays, see (Rasmussen, 1992). However, a brief description of the predominant types is included here. Conventional reed-relays consist of two electrodes mounted in a sealed glass tube. The electrodes are activated by an external magnetic field. In this type of relay, the mercury - or other metal, such as ruthenium or rhodium - is applied to the surfaces of the electrodes in a thin layer. This ensures the maintenance of a smooth surface because these metals, in contrast to others, do not form uneven surfaces, thereby establishing poor contact or causing arcing. Reed-relays are not to be confused with mercury switches, in which a larger quantity of mercury is free to roll around in a glass tube and, at certain angles, to form the conductor between the electrodes that are fused into the wall of the glass tube.

Domestic appliances
As early as 1994, DEMKO stated that mercury-containing thermal cut-outs were not used in domestic appliances, such as coffee machines and flat irons (Maag et al., 1996). The extent to which mercury has been used in these applications and when such use was discontinued is unknown. The discontinuation of such uses could be related to a German prohibition on the use of mercury in a number of household products in the mid-1980s (Rasmussen, 1992). Waste collectors say that they were still receiving, e.g., coffee machines containing mercury, during 2001.

Submersible pumps
A major manufacturer of submersible pumps states that, due to environmental considerations, it discontinued the use of mercury around 1996, and that this generally applies throughout the industry.

The consumption of mercury-containing level switches for submersible pumps, which have a mercury content of 6.8-13.6 g/pump, corresponding to a mercury consumption of 140-400 kg/year, was estimated at 20,000-30,000/year for 1982-83. Sales of submersible pumps for sewerage applications have dropped slightly and, according to the leading manufacturers in 1994, sales were marginal. However, level switches were manufactured in small quantities, although the manufacturer and quantity were not known (Maag et al., 1996).

The greater part of the sales of level switches is thought to be for use in sewerage applications. It is illegal to use mercury-containing level switches in clean water supplies. One supplier has stated that an average mercury content of 10 g/level switch is to be expected. Thus, we estimate that the annual mercury consumption from 1982 to 1993 varied between 200 and 300 kg of mercury (Maag et al., 1996).

Cars

Historically, cars have contained a number of mercury-containing components: ABS brakes, airbags, switches, lamps and instrument-panel displays. However, the use of mercury in certain components is gradually being phased out.

A major importer and dealer in cars is of the opinion that mercury is no longer used in ABS braking systems and airbags. This opinion is confirmed by a trade organisation (Rasmussen, 2002).

According to a 1993-94 assessment, less than 1% of all cars sold contained mercury-containing components. With respect to airbags, it was already known that mercury-containing sensors were being phased out.

The assumption that mercury is no longer used in ABS braking systems and airbags is reinforced by a study undertaken by the Danish EPA of mercury switches in cars; the study lists which car models use mercury switches and the year of manufacture of these cars. The most recent year mentioned is 1996. It is also seen that a number of makes that are well-known in Denmark are completely free of mercury switches (Grau, 2002; Sharp, 2003).

As of 1July 2003, an EU directive prohibits the sale of new cars containing heavy metals. A number of components listed in Annex II of the directive (European Parliament, 2002) are, however, exempt from this prohibition. As far as mercury is concerned, the relevant devices are discharge lamps and instrument-panel displays; this is apparent from a Commission decision (The Commission, 2002). The directive is implemented in a statutory order that sets requirements for the removal of mercury switches from cars before they are scrapped (The Danish Ministry of Environment, 2002).

Remote control of rail traffic
Mercury wetted relays, which are still permitted under the statutory order, can be used for repairs to older equipment. The mercury consumption in this application is not known (Danish National Railway Agency, 2003), but is only considered marginal. Mercury wetted relays are now substituted in new equipment. Instead, modern PLC equipment is used, in which microprocessors have rendered the relays obsolete.

Television sets
In the previous mass flow analysis of mercury, it was clear that the mercury in televisions was used in the cathode ray tube and in relays. According to a major manufacturer of cathode ray tubes, mercury has never been used in cathode ray tubes, and the use of mercury in relays ended in the 1980s. A processor of electronic waste has stated that the number of scrapped televisions containing mercury in 2002 was only marginal - roughly one/week - out of a total of about 3,000. The mercury content of the relays in televisions was estimated at less than 4 mg/set (Maag et al., 1996). As in the previous mass flow analysis, the mercury consumption for television sets is estimated at less than 2 kg.

Computing equipment
Personal computers are not expected to contain mercury-containing relays in quantities that significantly exceed the quantities found in older television sets. As

far as is known, such relays were used at the start of the 1990s, primarily in connection with data transmission, i.e., modems. Today, the conventional reed-relays in modems have probably been replaced by microprocessor technology. At the same time, most types of reed-relay are coated with materials other than mercury. Even if there are, in fact, one or a few mercury-containing reed-relays in every modem, the mercury consumption would scarcely exceed 5 kg/year (according to information collected for the previous mass flow analysis, a mercury content of the order of 0.1-10 mg of mercury/relay; according to information on sales of personal computers (IDC, 1999), sales of modems are roughly estimated at about 500,000/year).

Miscellaneous electronics
The use of mercury in electronics in general is considered to be marginal for the same reasons as were given for computing equipment. The report, *Elektronik - Erfaringsopsamling 1999* ("Electronics - Collected Experience 1999", Faber et al., 1999), states a mercury content of 0.0009% in printed circuit boards (based on information from the mid-1990s). Based on this information, the total consumption of mercury in relays used in miscellaneous electronic equipment in Denmark, including imported finished goods, is considered scarcely to exceed 10 kg/year.

Industrial plant
The Danish EPA has granted exemption for the sale of special mercury-containing rotating contacts in industrial plants. Such contacts are used when transmitting electrical power and signals to and from rotating machines. This exemption applies to a limited quantity until the end of 2002. The consumption for 2001 is assessed as being about 2 kg.

Flashing lights for rail traffic
Mercury-containing flashing light systems are manufactured in Denmark for the control of rail traffic and level crossings. Such use is still permitted. In 2001, 19 mercury tubes were consumed, each with a mercury content of 10 g. Thus, the total consumption is 190 g. This consumption varies from year to year, but 2001 was an average year in this respect. The consumption for the next five years is also expected to be around 190 g/year. This is significantly less than consumption in the same application in 1992-93 (50-100 kg of mercury).

Burglar alarms
The use of mercury-containing switches in burglar alarms for motorcycles and video tape recorders is considered to be marginal in Denmark and, as in the previous mass flow analysis, must be calculated as being less than 5 kg/year (Maag et al., 1996).

The consumption of gas chromatographs equipped with mercury-containing thermal cut-outs is only marginal in Denmark. Such equipment is only used in laboratories and has a relatively long life-cycle of 5-10 years. The consumption of mercury in this application is roughly estimated at less than 1 kg/year (as in the previous mass flow analysis; Maag, 1996).

Flashing lights in running shoes

Running shoes equipped with flashing lights controlled by mercury-containing switches were marketed in Denmark at the beginning of the 1990s, although imports stopped in the mid-1990s (Maag et al., 1996). A major importer confirms this and states that only shoes without mercury are imported (Bech, 2002). Similarly, Floyd et al., 2002, mention that substitutes have now been found for the mercury-containing switches in flashing shoes for children.

Total consumption
In summary, the total consumption of mercury in switches, contacts and relays can be assessed as being less than 24 kg/year.

Development trends
All information indicates that the use of moderately large mercury-containing switches and relays has been discontinued - or largely discontinued - with the possible exception of minor consumption for repairs to older equipment (cf. use in the remote control of rail traffic). On the other hand, it is difficult to assess the prevalence of mercury-wetted switches/relays although, as mentioned above, this is only a question of very small quantities of mercury/device. According to information from suppliers, reed-relays with mercury-wetted contacts can still be purchased although many types use other contact materials, and it is presumed that such relays are being replaced by microprocessor technology in many applications. As mentioned above, mercury wetted contacts and relays are still exempt under the Danish statutory order on mercury.

Disposal
The loss of mercury through the disposal of products is difficult to assess with any certainty, as such losses are mainly associated with applications that have been discontinued today. Any assessment of this loss must, therefore, make allowance for the historical magnitude of consumption, as well as for the probability that mercury-containing products are still in use.

Around 1992, the total consumption of mercury for electrical contacts, switches and relays was of the order of 200-400 kg/year, of which 200-300 kg was for submersible pumps. The total consumption does not include telephones, many of which apparently have a life-cycle in excess of 20 years, as used telephones and telephone exchanges are the source of most of the relevant collected mercury in switches, contacts and relays (see below).

Many of the products listed in the table may still be in use or in storage, from where they will gradually be discarded (the "box-room" effect). A long life-cycle is expected, for instance, for the mercury-containing switches in submersible pumps.

According to one waste collector, about half of all the freezers collected are equipped with mercury-containing switches. This collector, who receives about 20% of electronic waste in Denmark, collected about 10,000 freezers in 2001. If an average mercury content of 5 g/switch is assumed, this corresponds to a collected annual quantity of 125 kg of mercury from freezers in Denmark.

According to waste collectors, old telephones and telephone exchanges are one of the largest sources of mercury-containing contacts, switches, and relays in electronic waste. In recent years the telephone company TDC has, itself, collected an annual 800-1,000 kg mercury-containing contacts, switches and relays from telephones and telephone exchanges. All telephone exchanges have now been replaced by digital exchanges that contain no mercury, although some of the old, analogue installations are still to be found "inactive" around the country. On the assumption that the mercury content is 70-90% of the weight of the contacts, switches and relays, an annual 600-900 kg of mercury is collected by TDC in telephones and telephone exchanges. In addition, there is the mercury from telephones processed by collectors of electronic waste. If this is assumed to amount to 10-20% of the quantity collected by TDC, an annual total of 650-1,000 kg of mercury is collected with telephones and telephone exchanges. This is exported.

In addition, there is the mercury exported with telephones and telephone exchanges for reuse abroad. For the past three years, complete telephones have been exported for reuse. Such telephones were scrapped in earlier years. According to the exporter, about 10% of the exported telephones are considered to contain mercury. Calculating with 250 kg containers and assuming an average weight of 0.75-1 kg/telephone and an average content of 4-5 g of mercury/telephone, an annual quantity of 50-90 kg of mercury/year is exported in complete telephones.

Waste collectors state that printed circuit boards account for 9-10% of the total quantity of electronics (about 20,000 tonnes, according to the collectors of electronic waste). Assuming a mercury content of 0.0009% (Faber et al., 1999; Rambøll, Hannemann & Højlund A/S, 1995), this corresponds to 14-16 kg of mercury.

Certain old models of coffee machines contain 10-20 g mercury/machine. Based on information from a single waste collector, we consider that about 100 such coffee machines are collected every year. This corresponds to an annual 1-2 kg of mercury.

In addition, there are the previously mentioned contacts, switches and relays, which are considered to constitute a minor proportion of the collected contacts, switches and relays. The author is of the opinion that it is not unrealistic to calculate with 50-150 kg of mercury/year in other types of contact, switch and relay.

Summary of the annual collection of mercury-containing contacts, switches and relays:

Telephones and telephone exchanges	650-1,000	kg of mercury
Switches or contacts in freezers	100-150	kg of mercury
Coffee machines	1-2	kg of mercury
Miscellaneous	50-150	kg of mercury
Total collected (rounded)	820-1,300	kg of mercury
Exports of complete telephones	50-90	kg of mercury

All of this is exported; however, Kommunekemi has a temporary store destined for later export for re-processing (Naamansen, 2003; Hohberg, 2003).

It is probable that some of the mercury-containing contacts, switches, and relays end in refuse. The previous mass flow analysis estimated that <160 kg of mercury ends in refuse. This was a question of mercury in telephones, coffee machines, etc. As can be seen from the foregoing, the quantity of mercury collected with telephones is considerably greater than was previously thought to be the case. The life-cycle of other mercury-containing contacts and switches is also possibly significantly longer than 10 years, 20 years is perhaps more likely. The consumption of mercury in electrical equipment was assessed as being 160-520 kg/year in 1982-83. Less than 100 kg of this was in telephones (Hansen, 1985).

Mercury has also been found in the output of incinerator plants, i.e., mercury is still discarded in refuse. As a rough estimate, the quantity of mercury entering refuse is assessed as being 1030% of the collected quantity. This corresponds to 80-400 kg of mercury.

2.2.4 Thermometers

During the last decade, mercury-containing thermometers were principally sold as clinical thermometers and thermometers for controlling industrial processes, mainly the diesel engines of large ships (Maag, 1996). Today, however, mercury-containing thermometers have largely been substituted by electronic thermometers and thermometers containing non-mercury-containing metal mixtures.

Since 1994, it has been prohibited in pursuance of the first mercury statutory order to sell mercury-containing thermometers other than special-purpose thermometers (Ministry of Environment, 1994). It is also apparent from a letter that the Ministry of Health states in a statutory order on medical equipment that equipment, which has been subjected to EEC type approval, can still be marketed (Rüsander, 1994).

The most recent mercury statutory order, of 1998, specifies that such exemption covers (Ministry of the Environment, 1998):

- thermometers that have been subjected to EEC type approval (in conformity to Directive 76/764/EEC and subsequent amendments) until 30 June 2004 (approved clinical thermometers);

- special-purpose thermometers: marine industry, until 31 December 1999; combined heat and power stations, until 31 December 1999; calibration of other thermometers, until further notice, analytical equipment, until further notice.

Based on this information, we assume that thermometers that have been subjected to EEC type approval have been on the market throughout the period.

Clinical thermometers

The use of clinical thermometers containing mercury has dropped dramatically over the past 10 years. A large drop at the beginning of the 1990s was apparent as early as in the previous mass flow analysis. This is attributed to growth in the use of electronic thermometers and, possibly, glass thermometers filled with a liquid metal mixture consisting of gallium, indium, and tin (Maag et al., 1996).

Mercury-containing clinical thermometers are not manufactured in Denmark.

An importer of clinical thermometers states that pharmacists no longer purchase mercury-containing thermometers. The Danish Pharmaceutical Association confirms this, but cannot rule out that a few pharmacists purchase mercury-containing thermometers. The policy of not purchasing mercury-containing thermometers was introduced at the beginning of the 1990s, in anticipation of a ban (Riis, 2003).

The fact that mercury-containing clinical thermometers were largely sold to hospitals and other institutions was apparent from the previous mass flow analysis (Maag et al., 1996). We assume that mercury-containing clinical thermometers are no longer purchased for private use, although many such thermometers are probably still in use.

Importers of mercury-containing clinical thermometers for use in hospitals state that about 4,500 mercury-containing thermometers were sold in Denmark in 2001. Consumption of these items has fallen sharply - the corresponding figure was about 50,000 ten years ago. This information agrees with the account given in the previous mass flow analysis. According to importers, an average mercury content of 0.25 g/thermometer can be expected today. The reason for this drop in the quantity of mercury is that the glass industry is now able to manufacture capillary tubes more precisely. The total mercury consumption can be calculated as more than 1 kg.

Other types of thermometer
Consultation with a number of importers and dealers in thermometers for laboratory use reveals about 1,200 recorded sales of mercury-containing thermometers/year. As it is probable that there were some sales from other sources, it is estimated that a total of 1,000-1,500 mercury-containing laboratory thermometers were sold during 2001. These thermometers are expected to contain about 15 g mercury (based on information from suppliers and Norsk Renholds Verks-forening, 2001). This corresponds to a mercury consumption of 15-23 kg/year.

Mercury-containing thermometers are no longer manufactured in Denmark.

Importers state that many thermometers for use in analytical work contain spirit today, although mercury-containing thermometers are still used to a certain extent.

Disposal of clinical thermometers
In the case of the clinical thermometers used in hospitals and institutions, it is to be expected that practically 100% of the broken and discarded thermometers are collected and disposed of as chemical waste. In cases where it is not possible to

collect all of the metallic mercury from crushed thermometers, it must be assumed that the residue is collected, together with the wastewater from washing floors.

As the turnover of thermometers in institutions is considered to be quite fast (Maag et al., 1996), it is to be expected that the quantity destined for disposal more or less corresponds to the present consumption of about 1 kg of mercury, whereas a tiny quantity ends in wastewater and refuse.

In the case of clinical thermometers used in private households, it is logical to expect that only a modest proportion of the mercury is collected as chemical waste. In such case, it is probably a question of whole thermometers that are handed in to pharmacists. Other disposal alternatives include losses to refuse (whole thermometers, broken thermometers and mercury, which have been collected or picked up from floors by vacuum cleaners) and wastewater (from washing floor).

The life-cycle of clinical thermometers used in households can be significant, as many thermometers are only used a few times a year, or even less frequently. It is therefore assumed that the average life-cycle of such thermometers is close to 10 years.

Based on Maag et al., 1996, the consumption of mercury from clinical thermometers in households in 1991 was approximately 70 kg (1990, 100 kg; 1992, 20 kg and; 1993, 0 kg). To make the best estimate on the basis of the information available, it should here be assumed that the quantity disposed of in 2001 is equal to the quantity consumed in 1991, broken down as follows (corresponds to the previous mass flow analysis, in which Kommunekemi investigated received waste more closely):

Collected as chemical waste:	20-25 kg
Collected in refuse:	20-30 kg.

Disposal of other types of thermometer
In 1992-93, about 100 kg of mercury was also used in industrial thermometers and suchlike (Maag et al., 1996). In the previous mass flow analysis, laboratory thermometers were not accounted for separately, but were included in this total. In the case of industrial and laboratory thermometers, it also seems reasonable to assume an average life-cycle of about 10 years, even if there is probably considerable variation, depending on the application in question.

The disposal of industrial thermometers is probably mainly determined by the type of equipment in which the individual thermometer is used (mainly in motors). Mercury in such installations must primarily be expected to be collected by the recycling industry and secondarily, to be lost in wastewater and the waste stream through the dismantling of motors, etc.

As the best estimate on the basis of available knowledge, it will be assumed in this report that the quantity of mercury disposed of together with industrial and laboratory equipment corresponds to the consumption in 1992-93, broken down as follows (same proportions as in the previous mass flow analysis):

Collected as chemical waste or for recycling:	about 90 kg
Collected in refuse:	about 5 kg
Discharged to wastewater:	about 5 kg.

Disposal, total
Thus, we estimate that the following quantities of mercury from thermometers were disposed of in 2001:

Collected as chemical waste or for recycling:	100-120 kg
Collected in refuse:	20-40 kg
Discharged to wastewater:	20-40 kg.

NB: it goes without saying that there is considerable uncertainty in these estimates, and they should only be understood as an attempt to estimate the order of magnitude of the disposal of mercury from thermometers in Denmark.

2.2.5 Monitoring equipment

Sphygmomanometers
According to information given by a number of suppliers, an annual total of about 170,400 mercury-containing sphygmomanometers are still sold in Denmark. They have an average mercury content of about 5 ml, i.e., 70 g mercury. This corresponds to a total consumption in new sphygmomanometers of 12-28 kg of mercury/year.

Suppliers also state that by far the majority of these are sold to doctors in private practices. The hospital sector has substituted later models without mercury for mercury-containing sphygmomanometers to a greater extent than doctors in private practices. Sales to individuals with no medical background are considered only to consist of sphygmomanometers not containing mercury.

Older mercury-containing sphygmomanometers are only refilled to a very limited extent during calibration/maintenance. Recycled mercury taken from old sphygmomanometers is exclusively used for this purpose - only about 1 kg of mercury/year is used for this purpose.

Miscellaneous equipment
As was the case in the previous mass flow analysis, there is no certain information on the continued use of mercury in other monitoring equipment. However, the trend in consumption in recent decades has been strongly in favour of substitution by other technologies not containing mercury. For this report, a limited effort has been made to trace the continued use of mercury in these applications, although no sign has been found in connection with the collection of data that any significant use of mercury continues, e.g., in schools and industry. (In the case of industry, small quantities have been accounted for in other sections of this report.) This impression is also supported by the fact that the mercury statutory order and the requirement on permission to purchase toxic substances make the purchasing of mercury inconvenient and difficult. In principle, institutions of higher education

could be an exception to this, but no specific information on this is available. The consumption of mercury in monitoring equipment is considered to be minimal and should be roughly estimated at <20 kg of mercury/year.

Disposal
In the previous mass flow analysis (data from 1992-1993), the consumption of mercury for monitoring equipment was assessed as having been reasonably constant for many years, at about 500 kg. Our immediate assessment is that the life-cycles of these applications can be very long, and that a certain level of mercury use is apparently maintained, e.g., the sphygmomanometers of doctors in private practices. The same is possibly true of schools' and other educational institutions' stocks of mercury, e.g., in physics laboratories.

Thus, it appears probable that the disposal quantity reflects earlier patterns of use, rather than present patterns. However, it should be emphasised that there is no certain information on the magnitude of such disposal with respect to monitoring equipment. As a rough estimate, it seems probable that the annual disposal quantities from these sources could amount to 100-500 kg of mercury.

This is a question of applications which, as a rule, are deemed to be covered by effective mercury collection schemes. However, it also appears likely that small quantities of mercury are lost to refuse, air and wastewater in connection with the handling of broken equipment. In view of the lack of information on this, we consider that roughly the following distribution of disposal and loss could be of relevance:

Collected as chemical waste:	100-450 kg
In refuse:	20-50 kg
Emitted to air:	20-50 kg
Discharged to water:	20-50 kg.

2.2.6 Other applications in metallic form

Lighthouses
The Royal Danish Administration of Navigation and Hydrography operates 12 lighthouses, which were built or rebuilt in the latter half of the 19th Century. The lighthouses are equipped with powerful, rotating systems of lenses. The lenses weigh from between a few hundred kg up to four tonnes each. These lenses float in a bath containing from 6 to 200 kg of pure mercury, which minimises friction.

Minor quantities of mercury evaporate from these baths, which contain a total of about 1,400 kg of pure mercury. Assuming an evaporation of 0.5%, <10 kg of mercury is annually emitted to the atmosphere.

The Royal Danish Administration of Navigation and Hydrography annually delivers about 40 kg of mercury to Kommunekemi. Assuming that this quantity is to be replaced by new mercury, the annual mercury consumption is estimated at about 50 kg. The uncertainty of the above figures is assessed at about 20%.

2.2.7 Summary - metallic mercury

The available assessments and knowledge of the intentional use of metallic mercury in Denmark during 2001 and the disposal of mercury in these contexts are shown in Table 2.8.

Table 2.8
Consumption and disposal of metallic mercury used for intentional purposes in Denmark in 2001 (kg/yr of mercury)

Product/application	Consumption	Trend	Estimated disposal and loss (kg Hg/yr) to:				
	kg Hg/yr		Air	Water	Soil	Incineration /deposition in landfills	Chemical waste /exported
Dental fillings	1,100-1,300	Stagnating /falling	-	50-250	-	68-190	830-1,660
Light sources	59-170	Falling	1-9	-	-	20-120	60-80
Switches, contacts and relays	0-24	Falling	-	-	-	80-400	870-1,390
Thermometers	16-24	Falling	-	20-40	-	20-40	110-120
Monitoring equipment	10-50	Falling	20-50	20-50	-	20-50	100-450
Other uses as a metal	35-60	Stagnating	5-10	-	-	-	30-50
Total (rounded)	1,200-1,600		26-69	90-340	-	210-800	2,000-3,800

2.3 Use of mercury in chemical compounds

2.3.1 Batteries

Mercury is intentionally used in batteries of the types mercuric oxide, silver oxide, zinc/air and alkaline. An EU report (Floyd et al., 2002) shows the mercury content of the different types of battery. These figures apply to batteries sold in the EU. The figures have been confirmed by the Association of Danish Producers and Importers of Dry Batteries (Madsen, 2002). (In the following, the figures obtained from a Danish dealer are shown in brackets.) The mercury content of mercuric oxide batteries is about 32% (30-32%). The mercury in these batteries functions as the cathode. Silver oxide button cells contain about 0.34% mercury, alkaline button cells contain about 0.45% (0.2-0.5%) and zinc/air button cells, about 1.24% (1.1-1.2%). Mercury is added to these batteries to prevent self-discharge and to prevent gas from evolving during discharge, with resulting leakage or, in the worst case, explosion. All lithium batteries and rechargeable batteries have always been free from mercury (Floyd et al., 2002). About 70% of the European market for button cells consists of lithium button cells (Floyd et al., 2002). However, this does not apply to the Danish market, where zinc/air button cells are by far the most prevalent.

Import and the sale of batteries containing more than 0.0005% mercury by weight have been prohibited in Denmark since 1 January 2000. This prohibition applies to loose retail batteries and batteries included in products. However, button cells can contain up to 2% mercury by weight (Statutory Order No. 1044 of 16 December 1999 on certain batteries and accumulators containing dangerous substances). This statutory order is an implementation of an EU directive, i.e., corresponding prohibitions apply in the other EU countries.

Manufacturing in Denmark
Denmark has a limited production of alkaline batteries (not button cells). Based on information obtained from Statistics Denmark (2002b), and on the maximum permissible mercury content of this type of battery of 0.0005%, the consumption of metallic mercury for the manufacture of batteries in Denmark in 2001 is roughly assessed as a maximum of 9 kg/year.

Mercuric oxide batteries
This type of battery is no longer manufactured as it contains more than the permissible 2% of mercury. As the mercury is an active component of the electro-chemical system of these batteries, reduction of the mercury content is not possible in this type of battery (see The Association of Danish Producers and Importers of Dry Batteries website: www.batteri.dk). There is an annual consumption of about 1,000 mercuric oxide batteries in Denmark, see Table 2.9.

Loose retail batteries
Statistics Denmark gives some especially high figures for the importation of mercuric oxide batteries for the years 2000 and 2001 (Statistics Denmark 2001 and 2002). They have probably been incorrectly recorded.

The EPBA has calculated the consumption of different types of button cell for each country in Europe for the period 1996-2000. The Association of Danish Producers and Importers of Dry Batteries has subsequently estimated the consumption for 2001. The result for Denmark can be seen in Table 2.9.

Table 2.9
Consumption of button cells in Denmark (EPBA, 2001) and their mercury content (Madsen, 2001; Jochumsen, 2003)

							Hg %	
Items x 1,000	1996	1997	1998	1999	2000	2001	min.	max.
Mercuric oxide	361	358	219	15	1	1	30	32
Alkaline	340	1,205	440	1,361	888	1,000	0.2	0.5
Silver oxide	1,173	1,433	1,120	973	618	400	0.2	0.6
Lithium	401	1,411	525	638	636	700	0	0
Zinc/air	8,806	10.769	10,721	13,653	7,702	8,000	1.1	1.2
Total	11,081	15,176	13,025	16,640	9,845	10,101		

It can be seen from the table that the consumption of mercuric oxide button cells continues, and that zinc/air batteries constitute the greater part of the button cells. Zinc/air button cells are almost exclusively used in hearing aids (Jochumsen,

2003). The total number of button cells consumed in Denmark was about 10,000/year, for the years 2000 and 2001.

Button cells weigh from 0.2-4 g each. The most used alkaline button cells weigh about 2 g each, whereas zinc/air batteries are often a little smaller, 0.6-0.9 g each (information from a supplier). Assuming an average weight of 1.5-2 g (but 0.6-0.9 for zinc/air) for button cells, the sales figures correspond to an average consumption of button cells of 10-14 tonnes during the period 1996-2001, whereas the average for 2000 and 2001 was 8-11 tonnes.

Table 2.10 shows the consumption of button cells converted into kg of mercury. No allowance has been made for the fact that the mercury content of the individual types of button cell can have dropped during the period.

Table 2.10
Consumption of mercury in button cells in Denmark

Button cells (kg of mercury)	1996	1997	1998	1999	2000	2001
Mercuric oxide	160-230	160-230	99-140	6.8-9.6	0.45-0.64	0.45-0.64
Alkaline	1-3.4	3.6-12	1.3-4.4	4.1-14	2.7-8.9	3-10
Silver oxide	3.5-14	4.3-17	3.4-13	2.9-12	1.9-7.4	1.2-4.8
Zinc/air	58-95	71-120	71-120	90-150	51-83	53-86
Total	220-340	240-380	170-280	100-190	56-100	58-100

The annual consumption of mercury in loose button cells can thus be set to 58-100 kg. This corresponds to about 40% of the consumption in 1997. The drop since then is primarily due to a drop in the consumption of button cells containing mercuric oxide.

Large loose batteries
Batteries of types other than button cells can contain up to 0.0005% mercury. According to Statistics Denmark, about 3,000 tonnes of batteries other than button cells, lithium batteries and manganese dioxide batteries were consumed in 2001. With a mercury content of 0.0005%, this corresponds to about 15 kg of mercury. As many batteries are completely free of mercury today, 15 kg must be considered to be the maximum consumption.

Batteries supplied in finished goods
Mercuric oxide batteries are known to be used in many types of finished product, including hearing aids, photographic equipment, toys and clocks and watches.. For this reason, an attempt has been made to obtain information on the extent to which such batteries can be conceived of as being imported in finished goods.

Mercuric oxide batteries were previously used in hearing aids, but according to the Association of Danish Producers and Importers of Dry Batteries and Metaligen (Jochumsen, 2003), which supply batteries for all hearing aids in Denmark, today's zinc/air batteries can replace all mercuric oxide batteries for use in hearing aids

(www.batteri.dk). Hearing aids have largely been designed to operate with zinc/air batteries for the past 20 years (Maag et al., 1996).

Mercuric oxide batteries used to be widely used as the power supplies of photographic light meters (especially in single lens reflex cameras) in earlier years. These devices are now over 20 years old (Petersen, 2002). It is possible that there are still occasional replacement sales of such batteries. Visits to five photographic dealers revealed that two of them still trade in mercuric oxide batteries, albeit in very small quantities. The batteries were purchased in 2000 or earlier.

There are significant imports of batteries in inexpensive electronic articles (watches, pocket calculators, greeting cards (which play melodies), toys and suchlike, bicycle lamps and bicycle computers). The button cells in the toys supplied by the largest toy dealer in Denmark are mainly alkaline. This dealer imports both the button cells and the toys direct from the Far East and has received guarantees from the manufacturers, stating that mercuric oxide batteries are not used (Top-Toy, Vastrup, 2002).

An inspection of goods supplied complete with button cells has been conducted at a large supermarket owned by one of the national supermarket chains, at a bicycle dealer and at a shop specialising in low-priced goods from the Far East. Most of the goods with batteries contained stick batteries. Only a small number of the goods contained button cells. Based on the type designations printed on the packaging, or on the button cells themselves, the button cells used in toys and bicycle computers are alkaline cells, whereas the button cells in bicycle lamps are of the lithium type.

Thus, as was the case in the previous mass flow analysis, no examples were found of imported finished goods that contained mercuric oxide cells.

Total imports of button cells included in finished goods can be estimated as follows (numbers of items taken from Statistics Denmark, 2001 and 2001b):

Pocket calculators (predominantly alkaline - net imports: about 860,000 items/year, of which the author considers it reasonable to assume that 80% contain 1.5-4 g of button cells/calculator, with a mercury content of 0.45% by weight) = 4.6-12 kg of mercury/year;

Wrist-watches and pocket watches (silver oxide, alkaline and lithium - net imports: about 1.34m, all containing 0.3-1.5 g of button cells/item, with a mercury content of 0.45% by weight) = 1.8-9 kg of mercury/year;

Alarm clocks (typically alkaline - net imports: 189,000, of which about 25% are considered to contain 1.5-4 g of button cells, with a mercury content of 0.45% by weight) = 0.32-0.85 kg of mercury/year;

Toys and greeting cards (alkaline - sales, according to information from suppliers and our own estimate: about 1.1m batteries, with a mercury content of 0.2-0.45% by weight) = 3.3-7.3 kg of mercury/year.

The total quantity of mercury in button cells included with finished goods imported into Denmark can be estimated at 10-30 kg of mercury/year.

With respect to the stick batteries found in imported finished goods, the manganese dioxide and alkaline types of battery (the mercury content of which, as in loose retail batteries, is assessed as being tiny) are considered by far the most prevalent. The quantity of stick batteries in finished goods is roughly estimated to constitute about 30% of loose retail stick batteries, i.e., it corresponds to a mercury consumption of less than 5 kg/year.

Total consumption
As of 2001, the total consumption of mercury in batteries in Denmark can thus be assessed at about:

Loose button cells:	60-100 kg of mercury
Other loose batteries:	0-15 kg of mercury
Button cells in finished goods:	10-30 kg of mercury
Stick batteries in finished goods:	0-5 kg of mercury
Total:	70-150 kg of mercury

Development trends
Today's closer scrutiny of mercury, together with the prohibitions on more than 2% of mercury by weight in button cells and 0.0005% of mercury in other batteries, has resulted in a dramatic drop in the consumption of mercury in batteries. This is partly because mercuric oxide cells are very rarely used now, partly because the mercury content of the individual batteries has been reduced and, partly, because some batteries no longer contain mercury (applies to many stick batteries). According to the Association of Danish Producers and Importers of Dry Batteries, the complete removal of mercury from button cells is difficult due to the risks of leakage and possible explosion.

According to Statistics Denmark, the consumption of button cells in 2001 remains at the same level as in 1992, i.e., about 15 tonnes, whereas the consumption of loose batteries other than button cells has more than doubled since 1992, from 1,600 tonnes to about 3,700 tonnes.

Disposal
Certain delays must be expected in the disposal, in relation to the consumption, of the mercury in batteries. In practice, mercury-containing batteries were prohibited in Denmark from 1 January 2000. This means that a proportion could very well still have been in use in 2001, or stored by users with a view to later disposal. Up to 1 January 2000, alkaline batteries other than button cells were also permitted to contain more mercury: 0.025%, in contrast to the present maximum of 0.0005%. Consumption of the mercury in mercuric oxide batteries in 1993 was estimated at 280-430 kg, while the consumption for 1994 can be estimated at 440-600 kg (440 kg was recorded by The Association of Danish Producers and Importers of Dry Batteries, plus an estimated maximum of 160 kg imported through other sources, according to Maag et al., 1996). The total consumption of mercury in batteries in 1992-93 was estimated at 400-860 kg/year (Maag et al., 1996).

Consumption of the mercury in batteries has dropped sharply over the course of the past decade, which is especially true of mercuric oxide batteries. Table 2.11 below contains the known information on the consumption of mercury in mercuric oxide batteries.

Table 2.11
Available information on the consumption of mercury in mercuric oxide batteries

Consumption of mercury in mercuric oxide batteries	Consumption, kg of mercury 1)
1993 (Maag et al., 1996)	280-430
1994 (based on Maag et al., 1996)	440-600
1995, interpolated between 1994 and 1996	300-400
1996, Figures from Table 2.10	160-230
1997, Figures from Table 2.10	160-230
1998, Figures from Table 2.10	100-140
1999, Figures from Table 2.10	7-10

Note:
1) The figures have been rounded to take account of their inherent uncertainty.

There is no certain information on the average life-cycle of mercuric oxide batteries (cf. the previous mass flow analysis), but 4-6 years is not an inconceivable period for the time between purchase and final disposal, bearing in mind the fact that the light meters of older photographic equipment (which have a very low current consumption) have been one of the most important applications for mercuric oxide batteries (Maag et al., 1996). If we accept the consumption figures of Table 2.11, the collection potential for 2001 alone could, thus, very well have been in the interval 160-400 kg/year.

In addition, there is the collection potential of the mercury contained in alkaline stick batteries; a rough estimate is 20-40 kg of mercury, based on the trend in mercury concentrations and consumption between 1993 (about 60 kg, according to Maag et al., 1996) and 2001.

The consumption of mercury in types of button cell other than mercuric oxide cells remained reasonably stable between 1993 (70-160 kg according to Maag et al., 1996) and the approximately 60-150 kg/year shown in Table 2.11 for the years 1997-2000. The collection potential is assessed on this basis as being of the same magnitude, i.e., 60-150 kg/year.

Based on the foregoing information, the total estimated collection potential for mercury from batteries can be summarised as follows:

Mercuric oxide batteries:	160-400 kg/year
Alkaline stick batteries:	20-40 kg/year
Other types of button cell:	60-150 kg/year
Total:	240-590 kg/year

That a significant quantity of mercuric oxide batteries - as well as other mercury-containing products - was disposed of as late as 2000-01 is supported by the fact

that the quantity of mercury in refuse was still relatively high in comparison to the 2001 consumption of mercury (see Section 3.2.2, on combustible waste).

The batteries needed for hearing aids are paid for by the public sector. For this reason, there is only a single supplier of such batteries. However, the used batteries are not collected by any central body. The individual users dispose of their batteries themselves. Thus, it is to be expected that a large proportion of these batteries is disposed of in refuse.

Silver oxide button cells are mainly used in watches and watchmakers generally replace these batteries. These button cells are collected by a single firm, which exports the used batteries to England for recovery of the silver. The quantity of mercury collected in silver oxide button cells is 0.5-2.5 kg.

The report *Indsamlingssystemer for batterier - eksisterende erfaringer fra Danmark og udlandet* ("Collection systems for batteries - experience from Denmark and abroad") (Hansen and Hansen, 2002) has gathered the experience gained from six different collection systems in Denmark (the Municipality of Vejle, AVV, VEGA, REFA, Amagerforbrænding and R98, AKV and the Municipality of Bramming). Manganese dioxide batteries, and to some extent alkaline batteries, are deposited locally. 44-97% (calculated as an average of 60-80% in this report) of the collected batteries are thus deposited locally, whereas the remaining 20-40% of the collected batteries are sent to Kommunekemi.

The same report offers a provisional estimate for the collection potential of 0.41-0.54 kg/inhabitant. Of this, an average of 0.18 (0.16-0.26) kg/inhabitant is collected (Hansen and Hansen, 2002). This corresponds to a collection efficiency of 30-60%. By far the greater part of the remainder ends in refuse. Manganese dioxide and alkaline batteries constitute 72-97% of the collected quantity (Hansen and Hansen, 2002). This figure for the collection efficiency will be used for batteries other than button cells in the subsequent calculations of this report.

Kommunekemi, Elektromiljø and a private collector of silver oxide batteries received a total of about 2.5 tonnes of button cells in 2001. In comparison to the above average consumption of an estimated 10-14 tonnes during the years up to and including 2001 (a little lower in 2000 and 2001), this represents a collection rate for button cells of about 20-30%. By far the greater part of the remainder is considered to enter the refuse stream.

In 2001, Kommunekemi and Elektromiljø received a total in excess of 77 tonnes of batteries other than button cells. According to foreign trade statistics, the total consumption of other loose retail batteries was 3,700 tonnes. Thus, the quantity of batteries other than button cells received by Kommunekemi and Elektromiljø corresponds to about 2% of the consumption.

Based on the foregoing estimates, Table 2.12 shows the distribution of disposal quantities for mercury in batteries around 2001.

Table 2.12
Distribution of disposal quantities for mercury in batteries around 2001

Battery type	Estimated	Estimated	Mercury in	Mercury in	Collected mercury

	effectiveness of collection, %	collection potential, kg mercury	batteries - collected	batteries - added to refuse	in special local landfills 1)
Mercuric oxide button cells	20-30	160-400	32-120	40-368	-
Other types of button cell	20-30	60-150	12-45	15-138	-
Alkaline stick batteries	30-60	20-40	6-24	0-34	4-19
Total		240-590	50-189	55-540	4-19

2.3.2 Chemicals for laboratory and industrial use

Mercury and its compounds have traditionally been used for a wide variety of purposes in analytical laboratories. They have been used partly in the form of chemical reagents in various assays, partly in the form of electrodes used for measuring redox conditions (standard calomel electrodes) and partly in metallic form in a variety of analytical instruments used, e.g., in polarimetry, particle counting with so-called "Coulter counters," etc.

Mercury and its compounds have also been used in the chemical industry, e.g., as catalysts in heterogeneous catalysis in which mercury can, for instance, act as the carrier substance for sodium (which actually gives the catalytic effect) and in homogeneous catalysis, in which specific compounds of mercury behave as catalysts in a solution of the reacting substances. The Department of Chemistry at the Technical University of Denmark (Fehrman, 2002), as well as a number of leading industries that produce and use catalysts, have the impression that, although mercury can in principle be used for catalysis in a number of chemical processes, such use is only marginal today. In this context, mercury is considered to be "old-fashioned" chemistry, and much has been done to avoid the use of mercury for the sake of the environment. One major chemical industry also states that the few grams that they use every year are purchased through the suppliers of general laboratory materials, as the importation of these substances (classified as toxins) is too inconvenient from an administrative standpoint, when considered in relation to that industry's minimal consumption. The same industry is also of the opinion that this is generally the case.

The Department of Data on Chemical Products has provided information on a marginal consumption of mercury compounds in the manufacture of a number of different paint and enamel products; see the discussion of these below.

Consumption
Information has been gathered on the consumption of mercury and its compounds by a number of suppliers, which together are considered to cover up to 95% of the general laboratory market in Denmark (the coverage of mercury compounds could be lower). Such information as it has been possible to obtain is, however, considered to be rather sparse for which reason the uncertainty of the figures used in calculations is a little greater than is suggested by the above-mentioned degree of coverage.

The suppliers in question recorded total annual sales of about 14 kg of metallic mercury and 35-40 kg of mercury compounds in 2001 and 2002. The compounds included, e.g., the sulphate, nitrate, chloride, acetate, and salts of mercury, mercury-sodium amalgam, salts of phenylmercury and mercury-containing benzoic acid derivatives. There has also been a very small consumption of mercury-containing organic biocides in biological reagents intended, e.g., for immunological assays; this is a question of ethyl mercury compounds (thimerosal) of the type that are also used in certain vaccines (see the discussion below). As a spontaneous assessment, mercury sulphate, which is still used in standard COD analyses of wastewater, appears to constitute a significant proportion of the consumption of mercury compounds. Although the available information does not make a precise calculation of the mercury content of compounds possible, it is estimated on the basis of substance-specific accounts of part of this consumption to correspond to about 70% of the quantity of mercury compounds.

Because this is a question of data for a single year, because certain data has been given for 2002, and because there are assumed to have been certain sales from other suppliers, the total consumption in laboratories and in industrial chemical applications in 2001 must in this report be estimated at about 10-30 kg of metallic mercury, and 30-60 kg of compounds with a mercury content of about 20-40 kg.

Development trends
Both the suppliers of laboratory materials and contacts in industry consider that the chemical use of mercury has almost ceased in Denmark. The use of mercury sulphate in COD analyses also seems to be dropping, even if this type of analysis is still in use. For instance, a chemicals supplier has stated that mercury and its compounds are not stocked in Denmark, and that since 1999 there have been no sales of many of the mercury-containing substances listed in its catalogue. The mass flow analysis for 1992-93 recorded a sale of 60 kg of mercury in mercury compounds; on this basis, a total consumption of 60-120 kg of mercury/year is estimated for these applications (Maag et al., 1996).

Disposal
By far the greater part of the (limited) consumption of mercury for chemical purposes appears to be used in chemical analysis. The collection of environmentally hazardous chemicals from laboratories in Denmark is considered to be effective, and it is assumed in this report that consumed mercury is collected and disposed of as hazardous waste, and that the losses to wastewater, etc., are insignificant. It is to be expected that the greater part is sent to Kommunekemi. However, a smaller (but unknown) part, in the form of tubes/kits for COD analysis, is returned to the foreign suppliers, which state that it is recycled.

2.3.3 Other uses of chemical compounds

National Register of Chemical Substances and Products, Denmark
For this mass flow analysis, the National Register of Chemical Substances and Products, Denmark, has been searched for uses of mercury and its compounds in chemical products.

All in all, about 400 products containing mercury or mercury compounds, from 25 companies, have been reported since 1997. This is almost exclusively a question of such polymer-based products as hardeners and resins for plastic materials, plastic flooring materials, jointing compounds, etc. No reported products containing mercury are registered as laboratory chemicals.

According to the information obtained from the National Register of Chemical Substances and Products, Denmark, annual imports of mercury and mercury compounds in reported products constitute about 6 kg, of which by far the greater part is recorded as the compound neodecanoate-O)phenylmercury (CAS No. 26545-49-3). This is used in different forms in hardeners and resins for a number of plastic based materials. Based on the molecular weight of the above substance, a total of about 3 kg of mercury is imported.

A total consumption of about 1 kg of mercury (recorded as metallic mercury), for the manufacture of a number of different paint and enamel products, has been reported. In all, this concerns the manufacturing of over 300 products, with a total production of about 7,000 tonnes, distributed over many firms. Although the information given on the concentrations of mercury in the products is inconsistent, it suggests a level of a few mg/kg. No more detailed investigation has been made of the functions of mercury in these products (possible functions can include, e.g., preservatives and catalysts in hardeners).

Exports have been recorded of 0.7 kg of mercury in products, chiefly paint and enamel products in the same categories as were mentioned in the previous paragraph.

The information taken from the National Register of Chemical Substances and Products, Denmark, is based on reports and updates thereof provided on the initiative of the companies that market the relevant products for which reason, significant uncertainty must be expected to be associated with the reported quantities and information on use. Whether or not all of the reported products are still being used is not stated. If we consider the total numbers of products, i.e., including products reported before 1997, total imports amount to about 80 kg of mercury or mercury compounds, whereas the manufacturing and export figures are the same as those listed above. Of the 80 kg, the greater part, i.e., 48 kg, is recorded as "phenylmercuric oleate." No reports of products containing this compound have been recorded since 1997.

It is difficult to assess the magnitude of similar - but unreported - products that are possibly traded in Denmark, especially when seen in the light of the very small quantities involved. The use of mercury in paint and enamel goods is not permitted in Denmark (with the exception of catalysts until further notice) and there is some degree of regulation in the EU and the USA. Any widespread use of mercury in imported products is therefore considered unlikely.

Consumption and disposal
Based on the above information, the consumption of mercury in products of the types recorded in the National Register of Chemical Substances and Products, Denmark, is loosely estimated at between 5 and 50 kg/year.

It largely appears to be a question of products used in buildings or other types of structure. The mercury input will largely follow the materials to which the products are applied and is therefore counted as landfill. Previously mercury compounds in these types of product were primarily used as a preservative in latex paint and, possibly to a limited extent, in pigments. Both of these applications are considered to have ceased in Denmark. The use of mercury compounds in the Danish manufacturing of latex paint probably ended more than 20 years ago. The available information does not offer a basis for making a realistic estimate of the quantity of mercury that is disposed of with old building materials or structures. Thus, we have only calculated with the disposal of a quantity corresponding to the current estimates of consumption.

Fireworks
Certain sources state that mercury compounds are used, or have been used, in explosives and fireworks. Floyd et al., 2002, state that fulminate of mercury is sometimes used in detonators for these purposes.

However, a Swedish study states that mercury is not used in the modern manufacturing of fireworks, and that it was only possible to find trace levels of mercury in assays of six selected types of firework. The levels found represent a total consumption of mercury in fireworks of about 0.01 kg in 1998 (Göteborgs Miljöförvaltning, 1999).

The quantity and representativeness of the Swedish studies are insufficient to completely rule out the use of mercury compounds in fireworks. However, we assume that the consumption of mercury in this application is insignificant.

Vaccines and eye drops
Mercury is still permitted in vaccines and eye drops.

Mercury has not been an ingredient of children's vaccines since 1992. Mercury is used in certain vaccines against influenza and in certain vaccines for travellers (Japanese encephalitis). Mercury is an ingredient in thimerosal, which is a preservative containing an ethyl mercury compound. About half of the Danish vaccines against influenza contain thimerosal. The quantity of mercury in each vaccine is so small (50 µg of thimerosal/dose) that the total Danish consumption can be assessed as being less than 20 g of mercury/year.

According to the Danish Medicines Agency, mercury is not permitted in new pharmaceutical preparations. It is possible that individual eye-drop preparations contain mercury, however this only applies to a few isolated instances.

The total consumption of mercury in vaccines and eye drops is therefore assessed as being exceedingly small (<1 kg).

2.3.4 Summary - chemical compounds

The information available on the consumption of mercury in the form of chemical compounds, as well as losses in conjunction with the manufacturing and use of products containing mercury compounds, is summarised in Table 2.13.

Table 2.13
Consumption and disposal of mercury in chemical compounds for specific purposes in Denmark, 2001 (kg/yr of mercury)

Product/application	Consumption	Trend	Estimated disposal and losses (kg Hg/yr)				
	Kg Hg/yr		Air	Water	Soil	Consumed /landfilled	Other
Batteries	70-150	Falling	-	-	-	60-560	50-190
Laboratory chemicals	30-70	Falling	-	-	-	-	30-70
Medicinal applications	0-1	Falling	-	-	-	-	0-1
Other chemical applications	5-50	Falling	-	-	-	5-50	-
Total (rounded)	110-270	-	-	-	-	65-610	80-260

2.4 Mercury as an impurity in other products

2.4.1 Coal

Fossil fuels such as coal and oil have a small, natural mercury content. When burned, most of the mercury content of these fuels will accompany the flue gas. Thus, emissions of mercury to air will vary according to the mercury content of the fuels and the flue gas cleaning equipment used.

The period since 1990 has witnessed a drop in the consumption of coal and coke, which have been replaced by an increasing consumption of natural gas and renewable energy. 6.7m tonnes of coal were consumed for the production of energy in 2001, as opposed to 12m tonnes in 1994.

Coal's content of heavy metals varies to some extent, depending on the country of origin, although there is considerable variation between the individual mines of each country. In the most recent mass flow analysis, the mercury content of coal was estimated at 0.04-0.18 mg of mercury/kg (Maag et al., 1996). Newer analyses show a mercury content of 0.087-0.15 mg of mercury/kg of dry matter (Hald, 2002), from which the total consumption of mercury in coal can be estimated at 590-980 kg of mercury/year. Data from the industry suggests that the average quantity of mercury in the coal consumed is about 550 kg/year, although no interval of uncertainty is stated. In the following, calculations will be based on an amount corresponding to 600-1,000 kg of mercury/year consumed with coal, although the true figure is probably at the low end of this interval.

About 17% of the coal consumed is burned in plants equipped with semi-dry desulphurisation, 69% in plants equipped with wet desulphurisation, and 14% in plants that lack desulphurisation. The mass balances for heavy metals in Danish coal-fired power stations during 2000-01 are shown in Table 2.14.

Table 2.14
Distribution of mercury in quantity of coal consumed, together with residual products and emissions from Danish power stations, and combined heat and power plants. The data has been derived on the basis of mass balances for all Danish coal-fired combined heat and power plants.

kg mercury/yr	Quantity	Slag	Fly ash	Desulphurisation products	Emissions to air
Semi-dry desulphurisation	100-170	- 1)	50-80	30-40	30-40
Wet desulphurisation	410-690	0.4-0.7	200-340	93-150	120-200
No desulphurisation 2)	80-140	- 1)	40-70	-	40-70
Total	600-1,000	0.4-0.7	290-490	120-200	190-310

1) No mercury has been found in the slag from coal-fired combined heat and power plants equipped with semi-dry desulphurisation or from plants without desulphurisation.
2) Plants that lack desulphurisation usually burn a type of coal that has a low mercury content (Hald, 2002), but as it has not been possible to distinguish between these coals and other types of coal in the underlying data, no consideration is given to this in our calculations.

Emissions to air
As can be seen from Table 2.14, about a third (about 31%) of the mercury consumed is emitted with the flue gas. There appears to be a clear tendency for plant equipped with desulphurisation to emit relatively lower quantities of mercury than plant that lacks desulphurisation. Plants equipped with desulphurisation emit about 25-30% of the consumed mercury, whereas about 50% is emitted by plants without desulphurisation. The total emissions to air in 2001 are estimated at 190-310 kg of mercury. According to information from coal-fired plants, the true figure is at the low end of this interval. In the most recent mass flow analysis, the emission in 1992 was estimated at 300 kg of mercury, so there has been an overall drop in emissions in comparison to 1992. This drop is primarily because the consumption of coal has been halved.

Residual products
The residual products from coal firing include fly ash, slag/bottom ash and desulphurisation products. About 50% of coals' mercury content ends in fly ash, far less than 1% ends in slag and bottom ash whereas about 20% ends in desulphurisation products.

It has not been possible to retrieve data on the quantities of residual products from coal-fired plants for 2001, but data is available for 2000. As the total quantity of coal consumed in 2001 was the same as that consumed in 2000, it will be assumed that the quantities of residual products were the same in 2000 as in 2001. A national total of 554,000 tonnes of fly ash was produced through the burning of coal in 2000. It has only been possible to retrieve detailed information on the disposal of the fly ash produced within ELSAM's area, where the disposal is distributed as follows (Hald, 2002):

- about 32% used in cement production
- about 31% used in the production of asphalt and concrete
- about 30% deposited in landfills or used as filling (construction work)
- about 3% exported to foreign producers of cement/concrete
- about 4% placed in storage.

The 43,000 tonnes of slag/bottom ash were disposed of as follows:

· about 91% used as filling (construction work)
· about 9% was exported.

The products of desulphurisation are used for a number of purposes: plasterboard, cement, sulphur fertiliser, etc.

On condition that the disposal of the residual products from the ELSAM area are representative of the entire country, the disposal of mercury together with the residual products of coal firing in Denmark in 2001 can be stated as shown in the points below (rounded). This condition for distributing the quantities of mercury in residual products could, however, over- or underestimate individual streams.

For instance, the contribution to cement production - based on ELSAM's distribution - amounts to 97,160 kg mercury/year, despite the fact that the quantity of mercury in desulphurised gypsum and fly ash actually reused in cement production can be estimated at 3,591 kg. Whether or not the desulphurised gypsum and fly ash destined for cement production are exclusively taken from coal-fired plants is unknown. The difference could be due to the fact that cement production is only carried out at one location in Denmark, which means that transport costs also influence the extent to which transportation of the residual products is worthwhile. The difference between the two intervals is 62-70 kg of mercury, which quantity must be assumed to be distributed over one or more forms of disposal, i.e., asphalt, etc., landfill and filling, storage or export.

· Cement production: 40-90 kg of mercury/year.
· Asphalt, concrete, gypsum, etc.: 100-360 kg of mercury/year.
· Landfill and filling: 70-110 kg of mercury/year.
· Storage: 10-20 kg of mercury/year.
· Export: 20-30 kg of mercury/year.

2.4.2 Oil and biological fuels

This section accounts for the losses and circulation of mercury in oil and gas from offshore drilling platforms, losses and circulation at refineries as well as in the final gas and oil products. Drilling fluids and mud, which can also be of relevance with respect to mercury, are used in drilling for oil and gas. Figure 2.2 gives a collective overview of the results of this section.

Extraction of oil and gas
The production of oil and natural gas takes place in several fields in the Danish part of the North Sea. Primary separation of the extracted materials into water, oil, and gas phases is carried out at the drilling platforms. 20m m^3 of crude oil and 11,116m Nm^3 of natural gas (Danish Energy Agency, 2001). Natural gas and oil are transported onshore for refining and sale, whereas the water phase is discharged into the sea. However, a part of the produced water and natural gas is injected into the seabed to maintain the pressure needed to make the oil and gas flow towards the wells. A small quantity of the natural gas is burned at the

platforms, either as fuel or for flaring. An overview of what happens to the production of the Danish North Sea fields can be found in Table 2.15.

Table 2.15
Information on production and the subsequent streams of natural gas, crude oil and water from Danish fields in the North Sea (OSPAR, 2002; Danish Energy Agency, 2001).

Danish fields in North Sea	Natural gas, Nm^3/year, millions	%	Crude oil, tonnes/year, millions	%	Water, m^3/year, millions	%
Production (total offshore extraction)	11,116	100%	17	100%	21	100%
Injected into seabed	2,916	26%	0	0%	8	37%
Discharged into sea	0	0%	0	0%	13 1)	62%
Flared	270	2%	0	0%	0	0%
Fuel (offshore)	604	5%	0	0%	0	0%
Onshore	7,326	66%	17	100%	0	0%

1) About 443 tonnes of oil is discharged into the sea with the produced water (OSPAR, 2002).

The crude oil is transported onshore, where refineries refine it into finished products. There are three Danish refineries, which process an annual total of 9.4m tonnes of oil (*Olieberetning 2002* ("Oil Report 2002")). This corresponds to about 55% of the Danish production of crude oil being processed by Danish refineries, while it is assumed the remainder is exported. Natural gas is dried and recompressed offshore, after which it is piped onshore (Dalsager, 2002). According to Statistics Denmark, less than half of the natural gas delivered onshore is exported.

Mercury occurs in several different forms in oil, water, and natural gas. The ionic forms of mercury will generally follow the water phase, whereas the elementary and organic forms are retained in the carbon phase (Wilhelm, 2001). There is a general lack of information on the mercury contents of oil and natural gas, as well as on mercury's fate in products from offshore extraction and subsequent distribution onshore. This lack of data on mercury does not only apply to the Danish fields, but is generally characteristic of the other fields around the world, as are the great uncertainties associated with the existing data (Wilhelm, 2001).

Crude oil: with respect to the global market, Wilhelm (2001) reports a mercury content in crude oil of from about 1.5 mg/tonne to 3,000 mg/tonne. Wilhelm (2001) reports values from 2.5-9.3 mg/tonne for four assays of the crude oil extracted from the North Sea that is refined by an American refinery. A Danish operator in the North Sea reports values in the literature of 30-100 mg/tonne of mercury in crude oil. Thus, there is great variation in the mercury content of crude oil. Assuming that the mercury content of crude oil corresponds to the results of the four American assays of North Sea crude oil, we obtain a mercury circulation of 43-160 kg/year from the Danish sector. However, the values stated in the literature indicate a potential consumption of many tonnes/year for which reason, specific analyses of mercury from the Danish fields in the North Sea are necessary in order to assess the true circulation of mercury. The four assays considered to be representative of Danish oil from the North Sea will be used in the following estimates of the fate of the mercury found in crude oil.

Natural gas: mercury in natural gas almost exclusively occurs in its elementary form, at concentrations far below the saturation point, indicating that mercury does not exist in liquid form in the underground reservoirs (Wilhelm, 2001). There are no Danish analyses of the mercury content of the natural gas that is pumped up and processed by the drilling platforms. The concentration of mercury in the natural gas burned offshore is assumed by Wilhelm (2001) to be of the order of 1 $\mu g/m^3$, as is generally the case under American conditions.

Assuming that this concentration applies to Danish natural gas prior to transport onshore, it corresponds to a total circulation of about 11 kg of mercury/year in natural gas processed in Danish fields. All of the extracted gas is treated offshore; part of this is injected, a small proportion is burned and the remainder is piped onshore as ready-to-sell gas. About 2.9 kg of mercury/year is injected with gas, 0.9 kg of mercury/year is flared, and the remainder is piped onshore in gas. Elementary mercury adsorbs to metallic components and the mercury content of natural gas therefore reduces as the distance from the well increases (Wilhelm, 2001). Mercury precipitates in the pipelines, especially when transporting wet gas, which results in its complete disappearance from the gas when it is piped to onshore refineries (Wilhelm, 2001). The fate of the precipitated mercury is unknown, but Wilhelm (2001) estimates that it precipitates together with wax, sand, and other solid particles in the pipelines (gas sludge). The Danish natural gas system from the platforms to the shore is a dry system for which reason, there is a minor loss of mercury during transportation of the gas. Assays of Danish natural gas in the natural gas onshore network (ready-to-sell gas) have shown that the mercury content is below the detection threshold, where the detection threshold - depending on sample volume - is given as <0.1-0.8 $\mu g/m^3$ (Gruithuijsen, 2001). Wilhelm (2001) gives the mercury content of natural gas as <0.02-0.2 $\mu g/m^3$. Based on Gruithuijsen (2001), the circulation of mercury in the Danish consumer network is estimated at below 0.73-5.9 kg/year, and it is assumed that this quantity is emitted with flue gas when the gas is burned onshore. Based on the figures used here, the difference between this quantity and the quantity of mercury that leaves the drilling platforms is about 1.5-6.6 kg/year, and this is assumed to be precipitated in the pipelines - either during transportation onshore or at onshore gas treatment plants.

It is of relevance here to mention a study of the flow of mercury in The Netherlands, which states that the mercury content of Dutch natural gas is unusually high and that The Netherlands is the only country known to remove mercury from gas before it reaches the consumer (Maxson & Vonkeman, 1996). According to Maxson & Vonkeman (1996), German natural gas appears to contain higher concentrations of mercury than Dutch natural gas. The sludge from the extraction of natural gas is one of the two greatest and most concentrated sources of mercury in The Netherlands (Maxson & Vonkeman, 1996). The circulation of mercury from sludge, waste, and emissions related to the production of natural gas amounts to 8.5 tonnes in The Netherlands (Maxson & Vonkeman, 1996). Of this, the greater part is found in gas sludge, which as far as is known is separated at onshore plants in The Netherlands. As mentioned above, no specific information is available on the mercury content of Danish natural gas in connection with production, whereas the gas distributed to consumers is very well-documented

(Gruithuijsen, 2001). For the time being, there is no clarity as to how mercury follows material streams (discharges to water and emissions to air from the platforms, sludge or solid residual products that are brought onshore, etc.,) using the technology applied in Denmark. However, provisional information indicates that the mercury is perhaps chiefly separated from the gas at the platforms. The Dutch production of natural gas is about nine times greater than that of Denmark (IEA, 2002). However, this alone cannot explain the large differences.

Produced water: assays of produced water discharged from Danish fields in the North Sea reveal an average mercury content of about 0.3 µg/l (OSPAR, 2000). Based on this information, we estimate the circulation of mercury in produced water to be of the order of 6 kg/year. About 60% (about 4 kg of mercury) of this is discharged into the sea, and the remainder, about 2 kg/year, is injected into the seabed, cf. the distribution given in Table 2.15.

Processing at refineries
In most cases, there is no loss of mercury during the transportation of liquids, especially not of mercury in oil (Wilhelm, 2001). Thus, we estimate that, from offshore extraction to the refineries, there is no significant loss of mercury from crude oil. The total circulation at refineries is therefore considered to correspond to the total circulation of crude oil, which is estimated at 40-160 kg of mercury/year. As mentioned above, 9.4m tonnes of crude oil is refined by Danish refineries (Olieberetning 2002), corresponding to a circulation of about 2,090 kg of mercury/year. The remainder, which is exported with crude oil, corresponds to 20-70 kg of mercury/year. It should be noted that these quantities have been derived on the basis of four American assays of crude oil from the North Sea, but that there is great variation in the literature concerning the mercury content of crude oil. Thus, there is a clear need for mercury assays of Danish crude oil, in order to obtain reliable numbers.

There is only limited knowledge of mercury's fate in the refining process itself. At the refineries, mercury ends either in the finished products, in wastewater, in flue gas or in a solid waste product, e.g., in the form of a flue gas cleaning product or sludge from wastewater treatment. There is a general trend towards lower concentrations of mercury in the products as the distillation temperature rises (Wilhelm, 2001).

Wilhelm (2001) reports a Canadian study that discusses emissions from Canadian refineries. The Canadian study does not allow for a possible content of mercury in wastewater or in solid waste products, and it concludes that the quantity of mercury emitted to the atmosphere by Canadian refineries is the difference between the mercury in the crude oil and the mercury in the refined products. The Canadian study concludes that more than 90% of the mercury in crude oil is emitted to the atmosphere during the refining processes at Canadian refineries (Wilhelm, 2001).

Similarly, Wilhelm (2001) refers to an American study that investigates mercury's route through the refining process. This study found that 66% of the mercury in crude oil ends in the refined products, 18% is emitted to air, 13% ends in solid waste products and 3% ends in wastewater from the refining process (Wilhelm,

2001). However, significant uncertainties attach to the results that comprise the basis of the American study. With its point of departure in the American figures above, Table 2.16 shows the estimated circulation of mercury in crude oil at Danish refineries.

Table 2.16
Estimated circulation in Danish refineries

Use	Consumption 1)	Estimated disposal and loss (kg of mercury/year)			
		Air	Water	Landfill	Products
Crude oil	20-90	4-16	0.7-3	3-10	20-60

1) Calculations are based on an annual consumption of 9.4m tonnes of crude oil, which corresponds to the total capacity of Danish refineries (Olieberetning 2002). On the basis of no more than four assays of North Sea oil, a mercury concentration of 2.5-9.3 µg/kg in crude oil was also applied in the calculations (Wilhelm, 2001),.

Consumption

The total Danish consumption of oil products in 2001 amounted to 6.2m tonnes (Olieberetning 2001). No new Danish studies have been found of the mercury content in different oil products, for which reason calculation of the circulation is based on analyses taken from the most recent mass flow analysis, as well as on American analytical data. Table 2.17 shows the circulation of mercury in oil products in 2001.

Table 2.17
Circulation of mercury in oil products in 2001

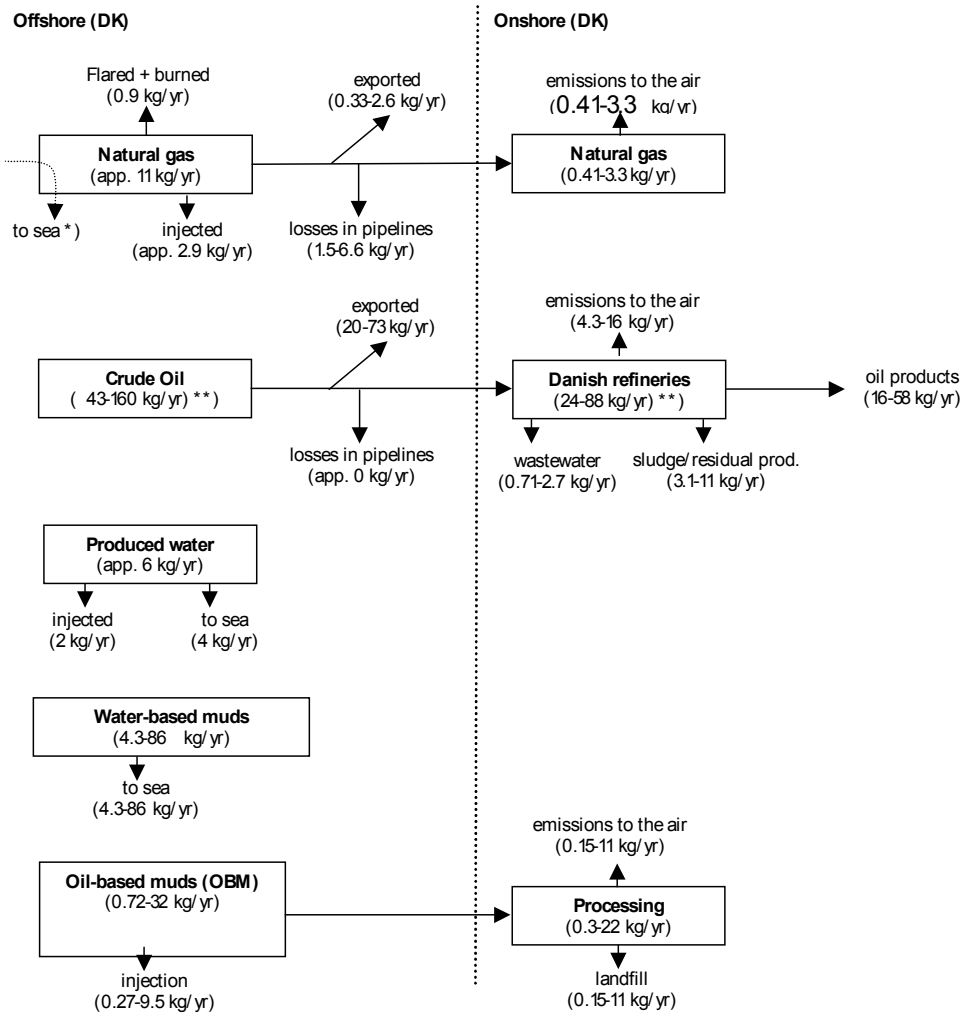
Product	Consumption, m^3 x 1,000	Consumption, Tonnes 1) 2)	Concentration, 2) mg Hg/tonne (ppb)	Consumption, kg Hg
LPG	130	71,000	0.2-30 3)	0.014-2.1
Petroleum	2,600	1,940,000	0.2-2 3)	0.39-3.9
Kerosene	8	6,400	50 3)	0.32
Fuel oil	1,300	1,100,000	0.2-10 3)	0.22-11
Auto diesel oil/gas oil	3,000	2,560,000	0.2-4 4)	0.51-10
Fuel oil and lubricating oil	590	580,000	1-5 5)	0.58-2.9
Total	7,600	6,250,000		2-30

1) Conversion factors for m^3 to tonnes based on (DONG, 2002).
2) For all products, the lowest concentration of mercury is based on the most recent mass flow analysis (Maag et al., 1996), whereas a reference to the highest concentration is given - as a note - for each individual product.
3) The highest concentration in the interval is based on (Wilhelm, 2001).
4) The highest concentration in the interval is based on the most recent mass flow analysis (Maag et al., 1996).
5) Wilhelm (2001) states a maximum content of 50 mg of mercury/tonne. However, the same maximum value (5 mg of mercury/tonne) as can be found in the most recent mass flow analysis (Maag et al., 1996) has been used in calculations.

The total Danish consumption of mercury in oil products amounts to 2-30 kg. As oil products are primarily burned without subsequent flue gas cleaning, the mercury content of oil products is assumed to be emitted to the air.

Fig. 2.2 gives a summary of mercury's route in products, from the North Sea and further to treatment and consumption onshore. It also shows the circulation of oil and water based drilling liquids and mud, which are described in more detail in the passage following the figure.

Fig. 2.2
Roughly estimated quantities of mercury in connection with the extraction of oil and gas in Denmark (based on flimsy data).



*) It is possible that there are considerable quantities of mercury in gas sludge from the production of natural gas, but there have been no Danish studies of this. According to Maxson & Vonkeman, 1996 there are high concentrations in Dutch and German natural gas. It is not possible on the basis of the information available to estimate these quantities, and it is assumed they are disposed of in the sea.

**) It should be noted that the literature reveals great variation in the mercury content of crude oil. This could potentially be a question of a mercury content in crude oil of several tonnes/year.

Drilling liquids and mud

Drilling liquids and a number of auxiliary substances (drilling and cementing chemicals) are used in drilling for oil and gas in the North Sea. Drilling liquids are used in exploratory and production operations. Drilling liquids are divided into water based and non-water based (i.e., oil-based drilling mud, OBM).

The use of drilling liquids is needed to counteract the pressure of oil and gas. Thus, drilling liquids contain materials of high density, e.g., barium sulphate, (barytes, $BaSO_4$).

The annual consumption of OBMs is about 5-8,000 tonnes, and it has been increasing in recent years in step with the increase in activity in the North Sea (Strandmark et al., 2002). The circulation of mercury in OBMs is a maximum of 33 kg of mercury/year and is based on the mercury content of the mineral, barytes, which constitutes about 80% of the drillings (Strandmark et al., 2002). The mercury content of barytes is given as being <5 mg of mercury/kg (Strandmark et al., 2002).

There is significant consumption of water-based drilling liquids - roughly estimated at 30,000-40,000 tonnes/year - and the mercury contribution from these drilling liquids is primarily considered to come from barytes, as is the case in OBMs. Four assays of water-based drilling liquids from Indonesia show a mercury content of 0.14-2.14 mg of mercury/kg (Wilhelm, 2001). This agrees with the mercury content of the barytes used in OBMs, which is <5 mg of mercury/kg (Strandmark et al., 2002).

Based on the assays of mercury in water-based drilling mud from Indonesia, the circulation of mercury in such mud is estimated here as being 4,386 kg of mercury/year. The circulation of mercury in OBMs is considered to be approximately 0.72-32 kg/year. The use and disposal of drillings from oil-based mud is regulated under the international OSPAR convention, which prohibits discharges to the sea (Strandmark et al., 2002). Drillings from OBMs are therefore disposed of in the Danish sector, either by injection into the seabed in the field or by transportation onshore for further processing, during which the oil in the drilling liquids is recovered in the form of base oil, whereas the solid material is used as landfill (Strandmark et al., 2002). As injection into the seabed is an irreversible process, it is impossible to recover the material thus disposed of (Strandmark et al., 2002). In 2002, all drillings from OBMs were transported onshore (Strandmark et al., 2002). The drilling mud is heated during the recovery process and some of its mercury content is considered to be emitted in flue gas. Assuming that half of the mercury is emitted and half is deposited, 0.15-11 kg of mercury/year is emitted to air and 0.15-11 kg of mercury/year is deposited. The circulation of mercury in drilling mud is outlined together with oil products in Fig. 2.2.

The way in which water-based drilling liquids are disposed of is not known, but it appears most likely that they are either discharged into the sea or injected into the seabed. This quantity is assumed to be disposed of in the sea, together with other offshore chemicals. With respect to the auxiliary substances, about 40% of the Danish consumption in the North Sea, corresponding to 55m tonnes, was discharged into the sea in 2001 (OSPAR, 2002).

Biological fuels
The consumption of straw, chipped wood and other wood products has remained largely unchanged during the period since the previous mass flow analysis, and it amounted to about 2.4m tonnes in 2000 (Danish Energy Agency, 2000). Of this, about 0.9m tonnes was consumed in power stations and district heating power stations, while the remainder was consumed in small farm installations, in industry, in private homes, etc.

Heavy metals are found in varying quantities in biomass, depending on how the biomass was cultivated and which plants it was based on. In general, there is only sparse information on the mercury content of biomass, and no newer data has been found on the mercury content of wood and straw in relation to the most recent mass flow analysis. The mercury content of pure wood is estimated (Christensen et al., 1997) at <0.007 mg of mercury/kg dry matter. A major Danish report from the Danish Technological Institute on mass balances for impurities at straw-fired plants covers detailed analyses of 12 different impurities, but mercury is not included (Evald, 1998). In the most recent mass flow analysis, the mercury content of wood is stated as being 1.0-1.5 µg/MJ, or 0.02-0.03 g of mercury/tonne dry matter (Maag et al., 1996). Assuming that the mercury content of straw corresponds to the mercury content of wood, the mercury circulation in biological fuels is about 18-76 kg/year.

Bottom ash (slag) and fly ash from a multi-cyclone or filter are formed when straw or chipped wood are burned in Danish utilities. Most utilities also have flue gas condensing equipment that yields sludge (Morsing & Westborg, 1996). The residual products are normally mixed in a common ash container (Morsing & Westborg, 1996).

When burning straw, the quantity of ash produced constitutes about 4-7% of the quantity burned (*Videncenter for halm- og flisfyring* ("Know-how center for straw and chip firing"), 1999) and, when chipped wood is burned, 0.4-3% ash is produced (*Videncenter for halm- og flisfyring,* 2000). Considered against the background of this information, an estimated 36,000-63,000 tonnes of straw ash, and 6,500-49,000 tonnes of wood ash, measured as dry matter, are annually produced. An annual mercury content of 0.9-0.16 mg of mercury/kg dry matter has been measured in a number of assays of straw ash from Danish utilities (*Videncenter for halm- og flisfyring,* 1999), whereas ash from chipped wood contains <0.05-1 mg of mercury/kg dry matter (*Videncenter for halm- og flisfyring,* 2000). There is no overall account of how this ash is disposed of, but roughly 2/3 is probably deposited as landfill, while the remainder is applied to agricultural soil. Under these circumstances, about 2.4-10 kg of mercury/year is deposited, while about 1.2-5 kg of mercury/year is applied to agricultural soil. The

remainder, which corresponds to about 14-61 kg of mercury/year, is assumed to be emitted together with flue gas.

2.4.3 Cement

Certain recoverable materials, as well as fuels that contribute the most significant quantities of mercury, are used in the production of grey cement. However, the lime used in the process also makes a contribution. The quantity of mercury that derives from the raw materials of cement production amounts to about 140-324 kg/year, and the greater part the mercury contribution comes from the fuels and fly ash. In 2000, 0.2m tonnes of fly ash was used in cement production, which quantity is the same as in 1992. The mercury content of this varies, from between 0.13 to 0.39 mg/kg.

Aalborg Portland produced 2.6m tonnes of cement in 2000. The production of grey and white cement as well as clinker constitutes 2.0, 0.5 and 0.1m tonnes/year respectively. These products constitute about 99% of total production and their mercury content is below the applied detection threshold of 0.05 mg of mercury/kg. The production of cement has remained stable in recent years. The mercury content of the total production is estimated at 54-130 kg of mercury/year, of which the main part is to be found in grey cement. The most recent mass flow analysis of mercury estimated the circulation of mercury in products from cement production at 60-220 kg/year (Maag et al., 1996).

Based on import and export information, the Danish consumption of grey cement is estimated at 1.3m tonnes/year. The consumption in 1992 was about 1.1m tonnes. Based on the available information, the Danish consumption of mercury in cement during 2000 is estimated at 26-65 kg, while it is also estimated that about 28-65 kg of mercury is exported in products.

The total deposited quantity of the mercury in residual products of cement production is estimated at 4.6-18 kg/year; it consists principally of filter dust.

Mercury evaporates at around 350°C, for which reason most of the mercury found in the raw materials evaporates in the cement production processes (Keating, 1997). The emission in flue gas is estimated by the authors at 70-170 kg of mercury/year.

The life-cycle of concrete is relatively long - typically from 30 to 75 years. Crushed concrete and other inorganic building waste is used as filling. About half of the quantity currently consumed in Denmark is a rough estimate of the quantity disposed of. Thus, we estimate that about 13-32 kg of mercury/year is deposited in landfills or used in construction works.

2.4.4 Agricultural lime and commercial fertiliser

Agricultural lime

According to reports to Statistics Denmark, the consumption of agricultural lime has dropped, from 1m tonnes in 1992-93, to 0.44m tonnes in 2001. The trend over the past 10 to 15 years has been towards a falling consumption of agricultural lime as a result of the falling consumption of nitrogen in agricultural soil. Nitrogen reduces the pH value of the soil, for which reason agricultural lime is added to stabilise the pH value. As the mercury content of agricultural lime is considered to be quite stable, we can estimate solely on the basis of the drop in consumption that the quantity of mercury released from agricultural lime to Danish agricultural soil has been more than halved since 1992-93. New assays of mercury in agricultural lime state that the mercury content is below the detection threshold of 0.01 mg/kg dry matter (Poulsen, 2002). Thus, the release of mercury in agricultural lime to Danish agricultural soil is estimated at <4.4 kg of mercury/year.

Commercial fertiliser
The mercury content of commercial fertiliser is very largely dependent on the fertiliser's phosphorus content. The mercury content of raw phosphate is extremely variable and depends on whether the raw phosphate is of volcanic or sedimentary origin. The introduction of a guaranteed level of purity, which guarantees a maximum mercury content of 0.2 mg/kg of fertiliser, now ensures minimal variation in the mercury content of the fertilisers. However, according to information from the producers, the mercury concentration in fertiliser is rarely this high; in most cases it is <0.05 mg/kg. The consumption trend has been dropping over the past 10 to 15 years. In fertilisation year 2000-01, the total consumption of commercial fertiliser amounted to 1.10m tonnes (Plant Department, 2001), which represents a drop of 0.3m tonnes/year in relation to fertilisation year 1992-93. About half of this fertiliser contained phosphorus. Based on the data collected, the total mercury content of commercial fertiliser is estimated at 11-36 kg/year. The most recent mass flow analysis estimated the quantity of mercury in commercial fertiliser at <50 kg/year.

2.4.5 Foodstuffs

The mercury content of foodstuffs derives from natural sources and from many years of man-made pollution. Mercury concentrates in the liver and kidneys of animals (Furness, 2001). Certain types of fish can contain much mercury, and the content varies widely from species to species, as well as between different waters. In Denmark, the average amount of mercury ingested in fish is 0.005 mg/week, although it is very dependent on the individual's consumption of fish (Danish Veterinary and Food Administration, 1996). The Danish Veterinary and Food Administration (1996) states that the Danish population's intake of mercury in all foodstuffs amounts to an average of 0.035 mg/week and, in the highest case, up to about 0.06 mg/week. Against this background, the total circulation in foodstuffs is estimated at 9.6-17 kg of mercury/year. The mercury that is not absorbed by the body ends mainly in wastewater (a small proportion is exhaled). Absorption by the body is extremely dependent on the form in which mercury is ingested. Thus, almost all organic mercury is absorbed after oral ingestion, whereas only 5-10% of the inorganic mercury compounds are absorbed (Danish EPA, 1987). The primary source of organic mercury in foodstuffs is fish. The half-life of mercury accumulated in the body is 7080 days (Danish EPA, 1987). Overall, the body will

therefore excrete the greater part of the mercury it ingests. Here, we expect a loss to wastewater corresponding to a circulation of 9.16-17 kg of mercury/year.

With the exception of mercury in the teeth, the quantity of mercury accumulated in the body will be minimal when death occurs. The distribution of mercury varies throughout the body. Thus, the following concentrations of mercury have been found: 8 µg/l of blood, 2 µg/g of hair, 4 µg/l of urine and 10 µg/kg of placenta (wet weight) (OECD, 1994). Some mercury will also be found in fat. Assuming that the entire body (60 kg) has the same mercury concentration as the hair, which is the highest of the above concentrations, a human body contains about 18 mg of mercury. There are about 60,000 deaths in Denmark every year. Using the above assumption, the bodies of the deceased contain a total of about 1 kg of mercury. This represents only a fraction of the mercury contained in teeth. For this reason, we have decided to ignore the quantity of mercury accumulated in the body at the time of death in places other than the teeth.

2.4.6 Miscellaneous consumer goods

In general, mercury must be expected to occur in greater or lesser quantities in practically all goods and products; this is partly due to the natural occurrence of mercury as a trace element and partly due to diffuse pollution by mercury.

The previous mass flow analysis roughly estimated the consumption of mercury as an impurity in goods at 70-1,400 kg of mercury/year (Maag et al., 1996). This quantity was estimated on the basis of the circulation quantities in solid waste destined for recycling, incineration or landfills, and on the assumption of a mercury content in miscellaneous goods of 0.01-0.02 g/tonne (Maag et al., 1996).

It appears reasonable to compare this value for mercury content to the background concentrations of mercury in coal (0.087-0.15 g/tonne), oil (0.0015-3 g/tonne), cement (<0.05 g/tonne dry matter), fertiliser ((<0.05 g/tonne dry matter) (see the previous section) and soil (0.04-0.12 g/tonne dry matter) (Stubsgaard, 2001).

The total quantity of waste in 2001 amounted to about 9.5m tonnes. Assuming a mercury concentration of 0.01-0.2 g/tonne,, this corresponds to 94-1,900 tonnes of mercury. Assuming that the circulation of mercury in waste corresponds to the consumption of impurities in different goods, the consumption of mercury as an impurity can roughly be estimated at 94-1,900 tonnes/year, of which 55-1,100 kg is contained in goods that are recycled. A more precise estimate of this quantity is not possible due to the lack of relevant information.

This quantity of mercury will probably sooner or later be chiefly disposed of in solid waste, a description of which can be found in Table 3.4.

2.4.7 Summary - mercury as an impurity

The available assessments of the mass streams of mercury as an impurity are summarised in Table 2.18.

Table 2.18
Consumption and disposal of mercury as an impurity in Denmark in 2001 (kg/yr of mercury)

Product group	Consumption (rounded)	Trend	Disposal and loss (kg mercury/yr) to:				
	Kg Hg/yr		Air	Water	Soil	Deposited & suchlike 2)	Other 3)
Coal	600-1,000	Falling	190-310	-	-	70-110	230-570
Oil products	2-30	Stagnating	6.3-50	5-7	-	6-13	-
Natural gas	0.4-3	Stagnating	1-4	-	-	-	2-7
Drilling mud	-	Stagnating	0.2-10	4.3-86 7)	0.27-9.5	0.2-10 4)	-
Biological fuels	20-80	Rising	10-60	-	1-5	2-10	-
Cement	30-70	Stagnating	70-170	-	-	20-50	-
Fertiliser and feeding stuffs	10-40	Stagnating	-	-	10-40	-	-
Agricultural lime	<4.4	Falling	-	-	2-4	-	-
Foodstuffs	10-17	Stagnating	-	9.6-17	-	-	-
All other goods	90-1,900	Various	-	-	-	40-780 5)	55-1,100 6)
Total (rounded)	740-3,100 1)		280-600	19-110	14-55	130-970	290-1,700

1) In the summation, 26-65 kg of mercury in fly ash was subtracted, as it is used in cement production and thus occurs twice in the table.
2) The column "Deposited & suchlike" includes residual products used for building and construction purposes, as well as mercury in waste that is burned or landfilled (cf. Section 3).
3) Mercury in residual products used in industrial production or exported for building and construction purposes (cf. cement production) and mercury as an impurity in goods that are recycled.
4) 0.3-9.5 kg of this is injected into the seabed in connection with drilling operations in the North Sea.
5) Expected to be disposed of in solid waste destined for incineration or landfills (see Table 3.4).
6) Mercury as an impurity in goods that can be reused, see Section 3.1.
7) The manner in which this quantity is disposed of is not known, but it is considered most likely that it is discharged into the sea or injected into the seabed.

3 Circulation in waste products

3.1 Recycling of mercury

It has not been possible to find firms that purchase metallic mercury in the recycling industry. The firms that did this when the last mass flow analysis was conducted quote prices, general inconvenience and small quantities as the reason for terminating such collection.

Instead, mercury is collected through municipal collection schemes, from which the main part is sent to Kommunekemi.

Metallic mercury comes from broken thermometers, monitoring equipment, laboratory and school chemicals and from district heating power plants. As far as can be ascertained, mercury stand pipes are no longer in use in district heating power plants but AVV, in Hjørring, received about 230 kg of pure mercury from such a plant as recently as 2000. This probably comes from a stand pipe that was not disposed of until 2000. Such individual cases completely change the total collected quantity of pure mercury, which for AVV in 1999-2001 amounted to 3-10 kg/year.

With the exception of Elektromiljø, which handles straight fluorescent tubes, there are as far as is known no firms in Denmark today that separate mercury-containing products. Sorting is the only activity carried out in Denmark. However, it is common to remove button cells and mercury-containing relays from printed circuit boards during sorting.

There is reason to believe that the quantity of mercury in fragmentation plants has dropped significantly.

This is partly due to a lower consumption of mercury in products, partly to the removal of mercury-containing units by car breakers, by TDC and by the recycling firms that process freezers, and partly to the collection of electronic scrap.

During the last few years, it has been mandatory for the car industry to remove mercury-containing switches from cars before scrapping. Removal is first carried out by the car breaker, followed by checks prior to fragmentation. For this purpose, there is a list of the car models that can contain such switches.

During the past three years, many of the whole telephones collected have been exported whole, instead of being cut up in Denmark.

Worn-out refrigerators and freezers are drained of CFC prior to scrapping. Any mercury-containing switches are also removed at the same time.

Mercury-containing parts are removed from electronic waste before apparatuses are scrapped.

In other words, it is normal for mercury-containing parts to be removed prior to the compression, division or shredding of metallic scrap. Nevertheless, some mercury-containing parts that will break and release mercury when compressed, divided or shredded can be overlooked. The temperature during shredding can reach about 300°C, at which a large part of the mercury will evaporate. In Denmark, there are five firms that operate fragmentation plant (or shredders) and about 30 firms that operate other mechanical divider plant (Danish EPA, 1998). 1,089,000 tonnes of Danish iron and other metallic scrap destined for recycling was collected in 2000 (Danish EPA, 2001a).

At the time of the previous mass flow analysis, the total emission to air from fragmentation plants was estimated at <50 kg of mercury/year. No improvement can be found in today's emission figures.

In the fragmentation and division processes, about 8% (87,000 tonnes) of the input scrap becomes waste destined for landfills, about 0.2% (about 2,000 tonnes) becomes waste destined for incineration and a very small fraction (wet-wash sludge) is sent to Kommunekemi as hazardous waste (Danish EPA, 1998). This quantity was estimated at less than 50 tonnes/year in the previous mass flow analysis.

Based on individual measurements in the waste, the previous mass flow analysis estimated the quantity of mercury in waste from fragmentation plants at about 200 kg. There is no improvement in today's release figures. Of this quantity, about 5 kg is incinerated, whereas the remainder is landfilled.

Re-smelting of iron and steel
Any mercury suspended in metallic scrap will be emitted to air in connection with re-smelting. It is known that the re-smelting of iron and steel in Denmark causes the emission to air of about 0.5 kg of mercury/year (year 2000). This is significantly lower than the 70 kg of mercury/year found in the previous mass flow analysis (Maag et al., 1996). This could be due to improved flue gas cleaning, as about 360 kg of mercury is found in residual products, of which about 310 kg is included in products that are recycled. In addition, there is roughly 14 kg of mercury in steel products.

Collected together with metallic scrap
Based on the foregoing, the mercury collected in metallic scrap amounts to about 625 kg/year.

Miscellaneous recycling activities
In all recycling activities, the mercury that occurs as an impurity in the recycled materials will also be recycled. With a total recycled quantity of approximately 5,544,000 tonnes (see Table 3.1), and a mercury content of 0.01-0.2 g/tonne (see Section 2.4.6), the quantity of mercury can be estimated as being approximately 55-1,100 kg/year.

3.2 Miscellaneous circulation in solid waste

3.2.1 Total quantities of solid waste

The total net waste production in Denmark - minus waste/residual products from secondary sources (processing plants, incinerator plants, composting plants/biogas plants and landfills) - amounted to about 9.5m tonnes in 2000 (cf. Table 3.1). The quantity of waste has been increasing, and the corresponding quantity in 1993 was about 6.8m tonnes.

3.2.2 Thermal treatment of waste

In 2001 (cf. Table 3.1), incinerator plants received about 2.8m tonnes of waste, about 1.4m tonnes of which was refuse (80% of all refuse) and about 0.35m tonnes was from bulky waste (48% of all bulky waste).

Table 3.1
Waste production in Denmark in 2000, broken down by source and type of treatment 1) (Danish EPA, 2001a)

Waste type	Recycled,		Incinerated,		Deposited,		Special treatment,		Total,
	tonnes x 1000	%	tonnes x 1000	%	tonnes x 1000	%	tonnes x 1000	%	tonnes x 1000
Refuse	260	15	1,400	80	88	5	0	0	1,748
Bulky waste	110	15	350	48	260	36	1.8	0.25	722
Garden waste	630	97	9.8	1.5	12	1.8	0	0	652
Industrial and commercial waste	4,500	72	980	16	740	12	1.1	0.02	6,221
Waste hazardous to environment	44	30	81	55	9.3	6.4	12	8.2	146
Special hospital waste	0	0	4	61	0.005	0.08	2.5	38	6.5
Total	5,544	58	2,825	30	1,109	12	17.4	0.18	9,496

1) The table shows the quantity of each type of waste entering a particular treatment stream from the primary sources. The primary sources are: households, trade and offices, manufacturing firms, building and demolition, roads and construction works, treatment plants and containers/waste transfer stations. This means, for instance, that all refuse is recorded under the waste type, "refuse," regardless of whether its source is households or, e.g., trade and offices. The table does not include waste/residual products from secondary sources (processing plants, incinerator plants, composting plants/biogas plants and landfills.

There are no up-to-date studies of the mercury content of refuse or bulky waste, but the total quantity disposed of by thermal waste treatment can be estimated from knowledge of the mercury content of the residual products from the incineration process and from the emissions in flue gas.

Questionnaires were sent to all Danish waste incinerator plants in conjunction with the preparation of this mass flow analysis. The waste incinerator plants were

requested to provide information on the quantity of waste incinerated, the type of acidic flue gas cleaning (wet, dry or semi-dry), types of filter, flue gas emission and concentrations of mercury in slag, fly ash and products of flue gas cleaning.

Based on the responses to the questionnaires, it has been possible to estimate the emission of mercury and its circulation in slag, fly ash and products of flue gas cleaning.

The available knowledge on the mercury content of residual products from waste-incinerator plants is shown in Table 3.2, whereas the emission to air in cleaned flue gas from waste- incinerator plants is estimated in Table 3.3. Based on the current practice with respect to the disposal of waste products, there are no requirements regarding on-going assays of residual products, for which reason it has not been possible to obtain up-to-date values for all waste incinerator plants. The available knowledge on residual products is therefore chiefly concerned with data for the period 1998-2001.

This report distinguishes between the following solid residual products of waste incineration:

- slag
- fly ash
- products of flue gas cleaning

Slag
Slag is the solid residual product that is removed from the bottom of the combustion chamber. "Slag" includes grate riddlings and boiler ash, which are typically mixed with the true slag. Slag contains iron and other metals to a varying extent, possibly with small quantities of unburned material. If the slag is to be kept for recovery, it will be processed by screening (possibly after crushing) and magnetic separation, from which three fractions are obtained:

- screened slag (screened and magnetically separated)
- scrap iron
- residuals, i.e., scrap slag (large unburned pieces and slag that has melted into large lumps)

Fly ash
Fly ash is the solid residue of combustion that can be extracted from flue gas without the need for any form of chemical separation. Fly ash is conventionally separated by means of electrostatic precipitators.

Products of flue gas cleaning
The products of flue gas cleaning result from the purging of acidic gasses from flue gas. Flue gas cleaning methods are normally divided into "dry," "semi-dry" and "wet" methods. In dry and semi-dry flue gas cleaning, the flue gas is passed through a lime suspension. The resulting sludge product is often handled separately from the fly ash. It has not been possible to obtain information on the quantities of residual products produced in 2001, for which reason the available residual product quantity data for 2000 has been used.

68,000 tonnes of flue gas cleaning products were removed from incinerator plants in 2000. By far the greatest part was exported for depositing in Norway or Germany. Thus, 85,700 tonnes was exported in 2000 (Danish EPA, 2001a). The difference between the removed and exported quantities is due to stock fluctuations. These exports are handled by two firms, i.e., Dansk Restprodukt Håndtering and Special Waste Systems.

The concentrations of mercury in the residual products, which are shown in Table 3.2, have been taken from responses to the questionnaires, from green accounts for the incinerator plants and from Dansk Restprodukt Håndtering, which handles a very large proportion of Danish residual products. It has not been possible to obtain sufficient data for 2001 and therefore data from a sizeable number of years has been used - however most data stem from the period 1998-2001. The data for dry and semi-dry residual products has been rather sparse, i.e., 3 and 4 assays, respectively. Much better data is available for wet residual products, a total of 14 assays, although two of them have not been included as they are considered to be highly unusual/incorrect (one sample was shown as being below the detection threshold of 20 mg Hg/kg dry matter and the other sample showed 1,400 mg Hg/kg dry matter). For this reason, 12 assays were used when determining the mercury content of the wet residual products. The mercury content of fly ash is considered to have been determined quite satisfactorily, as it was based on 16 assays. The mercury content of slag was determined on the basis of 10 assays.

In addition to the mercury that accompanies residual products, some mercury will be emitted with flue gas through the chimney. Flue gas is the waste incinerator plant's airborne emission.

It should be noted that today all waste incinerator plants are equipped with acidic flue gas cleaning as has been the case since 1995. Acidic flue gas cleaning was introduced for about 86% of all incinerated waste in 1992 (Maag et al., 1996).

In Tables 3.2 and 3.3, allowance has been made for the quantities of waste incinerated with the different types of acidic flue gas cleaning. The variations that can be seen in the mercury content of slag and products of flue gas cleaning could be a consequence of the fact that mercury distributes itself differently in different plants, as this distribution is affected by many chemical and technical factors. This circumstance has not been studied in more detail.

Table 3.2
Estimated quantities of mercury in residual products from incinerator plants in Denmark during 2001 1)

Residual product		Residual product quantities in 2001		
		dry matter, tonnes/yr	mg Hg/kg dry matter 7)	kg/yr Hg
Slags		422,000 2)	0.059-0.072	21-26
Flue gas cleaning products:				
From plant with dry process	Composite product	5,500 3)	1-5.1	5.5-28
From plant with semi-dry process	Composite product	24,700 4)	2.7-10	67-250
From plant with wet process	Fly ash	27,500 5)	2.5-6.4	69-180
	Flue gas cleaning products	4,800 6)	360-500	1,800-2,400
Total		485,000		2,000-2,900

The following conditions were applied when calculating quantities of residual products:

1) In 2001, about 3,014,000 tonnes of waste was incinerated, with the following distribution: about 259,000 tonnes (8.5%) in plant with a dry process, about 755,000 tonnes (25%) in plant with a semi-dry process and about 2,001,000 (66.5%) in plant with a wet process. It has not been possible to obtain information on the quantities of residual products produced in 2001 for which reason, the residual product quantity data for 2000 has been used. In 2000, 494,000 tonnes of slag, 5,500 tonnes of dry flue gas residual products, 25,000 tonnes of semi-dry flue gas residual products, 9,900 tonnes of wet flue gas residual products (sludge from flue gas cleaning) and 27,600 tonnes of fly ash (Nørby, 2003). The quantities for 2001 are expected to be basically similarly to those of 2000.
2) The slag production is shown as 494,000 tonnes in *Waste Statistics 2000,* which corresponds to a slag production of 16% of the incinerated waste. Based on the results of the questionnaire survey, the content of dry matter in slag was found to be about 85%.
3) Based on the results of the questionnaire survey, the content of dry matter in the composite product from the dry process was found to be 100%. In 2000, the production of the composite product from the dry process amounted to 21 kg of dry matter/tonne of waste. This value is at the low end of the interval given by Flyvbjerg & Hjelmar (1997), which shows a production of residual products from the dry process of 24-50 kg dry matter/tonne of waste.
4) Based on the results of the questionnaire survey, the content of dry matter in the composite product from the dry process was found to be about 99%. In 2000 the production of the composite product from the semi-dry process amounted to 33 kg of dry matter/tonne of waste. This agrees with the findings of Flyvbjerg & Hjelmar (1997), which give a production for the semi-dry process of 16-36 kg dry matter/tonne of waste incinerated.
5) Based on the results of the questionnaire survey, the content of dry matter in fly ash was found to be about 99.6%, which corresponds to a fly ash production of 14 kg of dry matter/tonne of waste incinerated. This agrees with the findings of Flyvbjerg & Hjelmar (1997), which give values of 10-30 kg of fly ash/tonne of waste.
6) Based on the results of the questionnaire survey, the content of dry matter in the flue gas cleaning product from the wet process was found to be about 49%, which corresponds to a production of wet flue gas cleaning products of 2.4 kg of dry matter/tonne of waste incinerated. This agrees with the findings of Flyvbjerg & Hjelmar (1997), which give an interval of 0.5-5 kg of dry matter/tonne incinerated waste.
7) An 80% confidence interval was used for setting the interval limits.

According to the latest mass flow analysis - data from this analysis is from 1992-93 - the total mercury circulation in residual products from waste incinerator plants amounted to 790-2,100 kg (Maag et al., 1996). As has been mentioned above, it has not been possible to use data from 2001, for which reason quantity data for 2000 has been used. For 2000, this quantity was determined as being 2,000-2,900

kg of mercury. Thus, there was an increase in the circulation of mercury in 2000 of 800-1,200 kg of mercury/year as compared to 1992-93. This increase is due to increases in the quantity of waste incinerated. In 1992, about 1.8m tonnes of waste was incinerated, as opposed to 2.8m tonnes in 2000, corresponding to a 50% increase. However, the increased quantity of incinerated waste cannot in itself explain why a greater quantity of mercury is retained in the residual products. The reason why more mercury is retained lies in the improved efficiency of flue gas cleaning.

Since 1995, legislation has required all waste incinerator plants to be equipped with acidic flue gas cleaning, whereas in 1992 about 14% of waste was incinerated in plants that lacked such flue gas cleaning. Moreover, relatively more waste was incinerated in plants with wet flue gas cleaning, which (cf. Table 3.3) exhibits significantly better retention of mercury in the product of flue gas cleaning than the dry and semi-dry processes. Thus, in 1992, about 33% of the waste was incinerated in plants equipped with wet flue gas cleaning, whereas in 2001 67% of waste was incinerated at plants equipped with wet flue gas cleaning.

Table 3.3
Estimated emission of mercury to air from waste incinerator plants in Denmark in 2001 1)

Flue gas cleaning	Incinerated quantity of waste in 2001, tonnes/yr	Mercury content of flue gas 2), mg mercury/Nm^3	Estimated total emission to air, kg/yr
Dry	259,000	0.0014-0.053	2.3-87
Semi-dry	750,000	0.012-0.12	57-570
Wet	2,000,000	0,017-0,029	210-370
Total	3,009,000		270-1,000

1) Based on the results of the questionnaire survey, there is an airborne quantity of 6,100-6,500 Nm^3/tonne of incinerated waste.
2) The measurements shown apply to dry flue gas at 0°C, 1,013 mbar and 11% O_2. Information on the mercury content in flue gas was gathered from the responses to the questionnaires sent to Danish waste incinerator plant in connection with this project.

There are significant uncertainties in the mercury content of flue gas emissions, which could be due to the method selected for quantifying the mercury in flue gas. Current legislation prescribes that the emission of mercury be measured in samples taken six times a year as the average of at least two samples taken over a period of one hour (Danish EPA, 1993). However, this method of sampling can only yield samples that represent a given moment and which make no allowance for possible operating disturbances or variations in the composition of the incinerated waste.

In comparison to the 1992 situation, when about 690-2,070 kg of mercury was emitted (Maag et al., 1996), mercury emissions from waste incinerator plants have dropped. This drop in emissions, which has occurred despite a 50% increase in the quantity of waste incinerated, is partly due to the fact that today all waste incinerator plants are equipped with acidic flue gas cleaning. It is also due to the fact that today's waste is more often incinerated in plants equipped with wet flue gas cleaning, which removes mercury more efficiently than plants equipped with dry or semi-dry flue gas cleaning.

3.2.3 Sources of mercury in waste destined for incineration and deposition in landfills

Balance, waste incineration
As can be seen from Tables 3.2 and 3.3, the total content of mercury in the waste incinerated in waste incinerator plants in Denmark in 2001 is estimated at (2,000 to 2,900) + (270 to 1,000) = 2,300 to 3,900 kg/year.

For the sake of comparison, Table 3.4 shows that, based on the estimates given for the mercury contribution to combustible waste from each of the individual areas of use, it is possible to account for about 270-1,800 kg/year. This could be related to the fact that the mercury content of products is dropping sharply. This makes the estimation of the quantities disposed of or lost very sensitive to the "box-room" effect, which is taken into account in the case of mercury-containing products. The box-room effect is an expression of the fact that, when products are worn out, they are stored by consumers for some period before they are disposed of. The available information does not make it possible to determine whether the streams have been underestimated or whether the results are due to general uncertainties in the accounts.

Table 3.4
Sources of mercury in waste destined for incineration and deposition in landfills

Source	Input Hg, tonnes/year	Percentage of total (rounded)	To incineration Hg, tonnes/year	To landfill Hg, tonnes/year
Teeth & misc. dental waste	70-190	10	64-180	4.1-11
Light sources	20-117	5	19-110	1.2-7
Switches & relays	80-404	18	75-380	4.8-24
Thermometers	20-40	2	19-38	1-2
Monitoring equipment	20.2-50	3	19-47	1.2-3
Batteries	55-540	22	52-510	3-32.4
Cement 1)	18-50	3	-	18-50
Biological fuels 1)	2-10	0	-	2.4-10
Oil products 2)	6-13	1	-	5.5-13
Coal 1)	68-110	7	-	68-110
Use as impurity	39-780 3)	30	28-560	11-220
Total (rounded)	400-2,300	101	280-1,800 4)	120-480

1) Used as filling or deposited.
2) Sludge from flue gas cleaning and from refinery tanks.
3) Includes the content of mercury as an impurity in various goods. Calculated for waste quantities of 2,825,000 tonnes and 1,109,000 tonnes, respectively, which are destined for incineration or deposition in landfills (see Table 3.1), and a mercury content of 0.01-0.2 g/tonne.
4) In addition, there is a small quantity of mercury in sludge incinerated at waste incinerator plants, see Section 3.4.2.

Deposition activities
No overall information is available on the quantity of mercury in waste deposited as landfill. Based on available knowledge, Table 3.4 estimates the quantity of

mercury that can be assumed to be deposited at controlled landfills in Denmark. There is no information that provides a check on this estimate. Apart from the quantities shown in Table 3.4, there is additional mercury in polluted soil which is landfilled and mercury in residual products from waste incineration, scrap management and wastewater sludge, see Table 3.11. Deposited mercury will gradually evaporate or be leached from landfills.

Leaching from landfills
The previous mass flow analysis estimated the quantity of mercury that is leached in percolate from landfills as being about 2.5 kg of mercury/year (Maag et al., 1996). No attempt has been made to find a better estimate for 2001. This percolate is sent to sewage treatment plants.

3.2.4 Treatment of biological waste

Figures for 2000 have been used here as the data for 2001 is still not available. In 2000, a total of about 0.45m tonnes of compost was produced, of which about 80% consisted of pure garden and park waste, 9% consisted of compost produced from household waste and 11%, of compost produced from wastewater sludge (Petersen, 2002). The statistics are based on reports from 133 composting plants and five biogas plants. Only biogas plants that treat organic refuse are included. The waste from plants that receive and chip garden and park waste without composting it are not included in the total quantities of compost (Petersen, 2002). Apart from compost, about 19,000 tonnes of screening residue was removed.

The average mercury content of compost based on refuse has been quantified at 0.11 mg/kg dry matter (five samples), whereas the compost from pure garden and park waste and garden/park waste mixed with sludge has been quantified at 0.08 (average of 10 samples) and 0.4 mg of mercury/kg dry matter (1 sample).

Based on the available information and with allowance for uncertainty in the data, we estimate the circulation of mercury in compost at about 29-44 kg/year, the greater part of which (more than 90%) occurs in compost produced from refuse. It is assumed that this quantity is released into the soil.

Screening residue mainly consisting of branches that do not degrade easily results from the composting process. Such screening residue has not been tested. As it primarily consists of branches, its average mercury content is probably lower than that of compost and we estimate the average mercury concentration as being roughly 0.02-0.09 mg/kg. The total circulation in screening residue is thus estimated at 0.32-1.5 kg of mercury/year.

In 2000, the quantity of liquid fertiliser produced that was obtained from treatment in biogas plants is estimated as corresponding to 0.2m m^3 (i.e., the production figure for 1999), with a dry-matter content of 3.5-5% (Petersen, 2001). It has not been possible to obtain any measurements of mercury in liquid fertiliser. Assuming that mercury is primarily bound to the dry matter, and that this material has a concentration corresponding to that of the dry matter in compost, we

estimate the total mercury content of liquid fertiliser at about 0.9-3.9 kg of mercury/year. This liquid fertiliser is used for agricultural purposes.

We estimate an overall circulation of mercury in residual products from biological waste treatment of 30-49 kg/year, which is released to soil.

3.3 Circulation in hazardous waste

In Denmark, collected mercury-containing waste ends at Kommunekemi, Elektromiljø (in Vejle), at the producers of dentists' amalgam filters, at the collectors of silver oxide batteries from watchmakers, at Renoflex, Nicha Miljøteknik or in more or less temporary local depots.

The latter applies, e.g., to alkaline batteries, which are deposited regionally (see the section on batteries). This also applies to mercury-containing waste collected by AVV, which covers nine municipalities in Vendsyssel. AVV stores the collected mercury-containing waste until it can find a recipient that does not recover mercury for recirculation, but that stores it so that it is removed from the global consumption of mercury (Nørregaard, 2002). In 2001, AVV collected about 20 kg of mercury (2.4 tonnes of mercury-containing waste) in thermometers, switches, light sources and as pure mercury. In 2000, AVV received about 250 kg of mercury, of which 233 kg came from individual district-heating power plants. This is stored locally.

The mercury-containing waste collected at Kommunekemi and Elektromiljø is exported to Germany or Belgium, respectively, where it is processed for reuse. However, Kommunekemi did not send mercury-containing waste to Germany in 2000 or 2001, but is temporarily storing it. Amalgam and amalgam filters from dentists are collected by the filter manufacturers and either sent to The Netherlands or Sweden for recovery. Part of the mercury-containing waste treated by Nicha Miljøteknik is received by Elektromiljø. The mercury-containing waste that is directly exported from Renoflex and Nicha Miljøteknik constitutes only small quantities and is included in Table 3.6, whereas Table 3.5 only deals with waste delivered to the largest recipient of mercury-containing waste.

Table 3.5 shows the quantities of mercury-containing waste collected by Kommunekemi, Elektromiljø, and AVV in 2001.

Table 3.5
Quantities of mercury-containing waste collected by Kommunekemi, Elektromiljø, and AVV

Waste type (tonnes)	Kommunekemi	Elektromiljø	AVV	Waste quantity (tonnes/yr)
COD liquid	12	-	-	12
Mercury-containing Kjeldahl liquid	11	-	-	11
Other pumpables, organically polluted	7.9	-	-	7.9
Mixed batteries	65	10	34	110
Mercury-containing batteries	2.3	0	0.16	2.4
Other solid mercury-containing waste	9.6	34	0.046	44
Light sources	160	440	2.4	590
Pharmacists' mercury collection boxes	110	-	-	110
Amalgam	-	-	0.058	0.058
Amalgam filters/amalgam	3.7	-	0	3.7
Total	370	480	36	890

Table 3.6 shows the estimated quantities of mercury delivered as hazardous waste in Denmark.

Table 3.6
Estimated quantities of mercury delivered as hazardous waste in Denmark

Waste type (tonnes)	Quantity of mercury (kg/year)
Mixed batteries	50-190
Amalgam	830-1,660
Light sources	60-80
Printed circuit boards	14-22
Switches in freezers	100-150
Telephones and telephone exchanges	650-1,000
Coffee machines	1-2
Other switches, contacts and relays	50-150
Thermometers	110-120
Mixed laboratory waste, incl. COD and Kjeldahl liquids	30-70
Various monitoring equipment	100-450
Mercury from lighthouses	30-50
Total	2,000-3,900

The mercury-containing waste delivered to Kommunekemi is disposed of as follows: manganese dioxide and alkaline batteries are cast in concrete and deposited at Kommunekemi's landfill. Metallic mercury is collected and exported for processing/reuse. Filter sludge and various electrical contacts and switches, monitoring equipment, and light sources are also exported by Kommunekemi

(periodically stored by Kommunekemi) to a mercury recovery plant. Other waste is exported for deposition in Germany.

Mercury-containing waste delivered to Elektromiljø is disposed of as follows: straight fluorescent tubes are processed in a closed system in Vejle, where the ends are cut off and the mercury-containing fluorescent powder is blown out. About 70% of the powder can immediately be reused by light source manufacturers, while 30% is sent to Belgium for processing together with other light sources and other mercury-containing waste. Carbon filters from plants that process straight fluorescent tubes are also sent to Belgium.

Mercury-containing waste delivered to AVV is stored by AVV in Vendsyssel, with a view to safe final deposition in the future.

Amalgam filters and mercury-containing waste collected by the manufacturers of amalgam filters are sent to Sweden and The Netherlands. Some of the filters are emptied in Denmark before their content is sent to Sweden and the filters are cleaned for reuse. There are no measurements of the emissions resulting from this emptying and cleaning. We estimate that about 1-2% of the mercury is emitted.

Kommunekemi has also informed us that the incinerator plant emitted <1.8 kg of mercury to air, 0.103 kg of mercury to water (direct discharge), 0.04 kg of mercury to wastewater, while 7.6 kg was deposited in Kommunekemi's landfill together with ash and filter cakes.

In summary, the following applies:
about 5-11 kg of mercury is emitted to air;
<1kg is discharged to water;
about 23-33 kg of mercury is deposited annually (including deposition at AVV);
about 2,000-3,900 kg is exported annually (in practice, exports do not occur every year, but the waste is temporarily stored and only exported when a suitable quantity has accumulated).

Waste oil
As there is no data for 2001, data for 2000 has been used. In Denmark, many waste oil fractions are collected for treatment. According to *Waste Statistics 2000* (Danish EPA, 2001), about 19,500 tonnes of recoverable oil was collected, which consisted of engine oil, gear oil, hydraulic oil, lubricating oil, etc. Of this, about 12,500 tonnes was burned in district heating power plants and about 6,912 tonnes was recovered.

In addition, about 14,000 tonnes of other oil-based products, including the output of petrol interception traps, oil separators, oil emulsions and other oil-based products (Danish EPA, 2001a), was collected. These products generally have a high content of water, so the actual quantity of oil is considerably lower.

Based on information from the industry, we estimate the average mercury content of waste oil at 20-52 mg/tonne, from this, the total circulation of mercury in waste oil can be roughly estimated at 0.68-1.8 kg/year.

The residues from the refining of waste oil, as well as from waste containing fuel oil, cutting oil and coolants, are used in cement production and are therefore included in the mass balance for cement, see Section 2.4.3.

An estimated 4,000 tonnes of waste oil, which corresponds to <0.2 kg of mercury/year, is disposed of by Kommunekemi.

3.4 Circulation in wastewater and wastewater sludge

3.4.1 Wastewater

Mercury and wastewater will be calculated from the following point sources:

- sewage treatment plant
- storm water outflows, from overflow structures and areas with separate sewer systems for wastewater and rain water
- industries with special discharges
- rural areas

The total quantity of wastewater discharged through municipal sewage treatment plants amounted to about 720m m^3 in 2001, whereas storm-water discharges diverted around sewage treatment plants amounted to about 200m m^3 (Danish EPA, 2002).

The quantification of xenobiotic substances in wastewater is carried out under the National Programme for Monitoring of the Aquatic Environment (NOVA 2003), and was most recently reported in the publication *Punktkilder 2001* ("Point Sources", Danish EPA, 2002).

Sewage treatment plants
Measurements of xenobiotic substances and of heavy metals are carried out at selected sewage treatment plants, which the Danish EPA considers to be reasonably typical from the viewpoint of the management and composition of wastewater in Denmark (Danish EPA, 2002).

Current data is available for 37 plants, for the period 1998 to 2001. Wastewater from these plants represented about 45% of the total quantity of wastewater. The industrial contribution in the influent to the 19 plants at which xenobiotic substances and heavy metals were measured, averaged about 35 % which corresponds reasonably well to the national average. 33 of the 37 plants for which xenobiotic substances and heavy metals were measured are designed for the removal of nitrogen and phosphorus and they generally purify the water better than is specified by the current requirements. Four of the 37 plants are small and use mechanical and mechanical-biological treatment processes.

The averages of the measured quantities, as well as the 5th and 95th percentiles of the inflow and discharge are shown in Table 3.7. It can be seen that there is significant variation in the measured values.

Table 3.7
Averages and percentiles for heavy metals in inflows to, and outflows from, sewage treatment plants, 1998-2001 (Danish EPA, 2002)

Average	Inflow (µg mercury/l), 5th percentile	95th percentile	Average	Discharge (µg mercury/l, 5th percentile	95th percentile
0.5	0.1	1.6	0.17	0.02	0.39

It should be noted that, although the percentiles give information on the scatter in the data, they say nothing about the precision with which the average is determined, as this depends on the number of samples taken.

Based on the concentrations shown in Table 3.7 and the quantities mentioned above, the total discharge from sewage treatment plants is roughly estimated at 14-280 kg of mercury/year, with an average value of 120 kg of mercury/year.

Similar calculations based on the average concentration of mercury in the influent, i.e., of 0.50 µg/l, show that the sewage treatment plants should receive about 360 kg of mercury. If the average values are considered, about 120 kg of mercury is discharged to recipients and it should therefore be possible to find the remainder, about 240 kg, in the sludge. When the uncertainties are taken into consideration, this quantity agrees with the calculated quantity in wastewater sludge from municipal sewage treatment plants, which is discussed later in this section. Based on a very large number of assays conducted in sludge, we estimate an annual total of about 150-230 kg of mercury in the sludge. The total quantity of mercury in sludge is assumed to have been determined with considerable certainty because of the large number of sludge samples. On average, 53% of the mercury content of wastewater is retained in sludge.

Table 3.8
Sources of mercury in municipal wastewater

Source	Estimated quantity, kg Hg/year	Comments
Atmospheric deposition	12	1)
Percolate from landfills	2.5	See Section 3.2.3
Dental clinics	50-250	See Section 2.2.1
Thermometers	20-40	See Section 2.2.4
Oil refineries	0.7-2.7	See Section 2.4.2
Faeces and urine	9.6-17	See Section 2.4.5
Monitoring equipment	20-50	See Section 2.2.5
Miscellaneous	?	2)
Total (rounded)	110-370	

1) The atmospheric deposition is calculated on the basis of a sewerage area of 1,718,000 m^3, on which there is an annual mercury precipitation of about 7 mg/m^3 (Kjølholt et al., 1998).
2) There may still be a considerable quantity of mercury in Danish sewer systems, from which it is only released slowly by continuous erosion, or quickly in connection with flushing of the sewers. Thus, an examination of the sources of wastewater sludge with a high mercury content reveals that accumulated mercury in sewers, which results from historical discharges from district heating power plant, is often the cause of the high concentrations of mercury (Markmann et al., 2001).

For the sake of comparison, there is an estimated 360 kg of mercury/year, calculated on the basis of the concentrations in the influent to sewage treatment plants. In other words, the results agree quite well. Part of the explanation of the difference could be the slow release of mercury accumulated in sewers from earlier discharges, see also Table 3.8, Note 2. The figures could also indicate that the current discharges from dental clinics are in truth at the high end of the interval studied.

Storm water outflows
Storm water outflows can be subdivided into separate discharges of surface water and overflow from areas with combined sewer systems for wastewater and rain water (especially old urban areas), which consist of a mixture of surface water and wastewater. Discharges from areas with combined sewer systems for wastewater and rain water contain not only surface water but are a mixture of municipal wastewater, re-suspended sewer sediment and biofilm, as well as surface run-off. Effluent from areas with separate sewer systems for wastewater and rain water chiefly contains surface water from built-up areas (roofs, roads, etc.,) and re-suspended material from sewer pipes. The actual process of quantifying the volume and content of a storm water outflow demands advanced test equipment. As such outflows only occur as a result of heavy precipitation, it can be very difficult to plan quantification programmes. The volumes shown below are based on model calculations; considerable uncertainty is associated with the calculation of storm water outflows, which becomes apparent when these calculations are compared to actual measurements (Danish EPA, 1997).

In 2001, 149m m^3 of water was discharged in separate storm water outflows and 36m m^3, through overflow structures, both from areas with combined and separate sewer systems for wastewater and rain water (Danish EPA, 2002). A large study of Danish and international discharges through overflow structures has ascertained that the information available on the content of xenobiotic substances in sediment and biofilm is particularly limited (Arnbjerg-Nielsen et al., 2002). According to the study, there is reason for assuming that the heavy metal content of biofilm and sediment in sewer systems from catchment areas with combined sewer systems for wastewater and rain water is comparable to - and in some cases higher than - the corresponding quantity in the particles from wastewater and urban surfaces. The estimated concentration interval for mercury in overflow water is given as 0.05-0.2 µg/l (Arnbjerg-Nielsen et al., 2002). This interval appears reasonable in relation to the concentration found in inflows to sewage treatment plants, i.e., an average of 0.5 µg of mercury/l. Assuming that this interval applies to the total quantities from storm water outflows and overflow structures, the total discharge in conjunction with rain events in 2001 is estimated at 10-41 kg of mercury.

However, it should be noted that some mercury is retained in basins and removed in conjunction with the cleaning of the basins. There is a clear tendency towards more areas being drained through discharges over basins, both in areas with combined and separate sewer systems for wastewater and rain water. Thus, within the areas with combined sewer systems for wastewater and rain water, there was a 58% increase in the built-up area from which water is discharged via basins, while there has been a 19% drop in the areas from which discharges occur without basins

(Danish EPA, 2001b). No studies are available of the magnitudes of the quantities of heavy metals retained in the basins.

Industries with direct discharge
Sampling for heavy metals was only carried out at seven selected firms in 2001, and an account of the quantities discharged is, thus, not applicable to Denmark as a whole (Danish EPA, 2002). About 10% of all the wastewater samples taken for mercury showed concentrations of more than 10 times the stated quality requirements on aquatic areas. In these cases, it is to be expected that the requirements have generally not been satisfied, and that the concentrations must be considered critical (Danish EPA, 2002).

Information was collected for the year 2000 from 162 firms, 82 of which discharge heavy metals and/or xenobiotic substances (Danish EPA, 2001b). In addition, there is information on 14 firms, which are assumed to discharge heavy metals and/or xenobiotic substances and which are not included in the account (Danish EPA, 2001b). The total discharge for 2000 is estimated at 1.9 kg of mercury, and a maximum of 3.3 kg of mercury (Danish EPA, 2001b).

In 2000, about 74m m^3 of wastewater was discharged by special industrial dischargers, which - in comparison to the quantities mentioned above - corresponds to a mercury content in wastewater in excess of 26 $\mu g/m^3$. In 2001, about 65m m^3 was discharged by special industrial dischargers and the total discharge for 2001 is, thus, estimated at 0.42-2.9 kg of mercury.

Rural areas
Properties in rural areas, villages and summer cottage areas are often not connected to combined sewer systems for wastewater and rain water but can have water treatment facilities, such as septic tanks, which release to soil or field drainage systems. Wastewater drainage from all municipalities is used in estimating water consumption and the total discharge of mercury (Danish EPA, 2002). No information on the quantities of mercury discharged from rural areas is available for 2001. The figures must be expected to be similar to 2000 figures, when the discharge was estimated at 25 kg of mercury/year. Because of uncertainties, this study estimates the total discharge in 2001 13-38 kg of mercury.

The total discharges of mercury from point sources to the aquatic environment are summarised in Table 3.9.

Table 3.9
Discharges of mercury from point sources to the aquatic environment in 2001 - based on information for 2000 and 2001 (Danish EPA, 2001b) and (Danish EPA, 2002).

Source	Discharges of wastewater, m^3 x 1m	Average concentration, µg Hg/m^3	Discharge, kg Hg/year
Sewage treatment plants	720	20-390	14-280
Overflow structures	39	50-200	2-7.9
Separate storm water outflows	164	50-200	8.2-33
Industries with direct discharge	65	6.4-45	0.42-2.9
Rural areas	33,310	-	13-38
Total (rounded)	34,298		37-360

3.4.2 Wastewater sludge

Sludge must be disposed of after the completion of processing by waste treatment plants. Until 1995-96, there were in principle three main options for the final disposal of wastewater sludge, i.e., application to agricultural soil, incineration in external or internal plants and deposition at controlled landfills.

Developments in wastewater sludge disposal have meant that, during the last few years, other options for the disposal of this sludge have been used which do not fit in with the above main options.

The number of sludge mineralisation plants has increased noticeably over the past few years. Municipalities consider sludge mineralisation to be an alternative method of sludge disposal. Mineralisation plants are expected to be able to store sludge for up to 10 years, before it is necessary to decide whether it should be applied to agricultural soil, incinerated, or deposited at controlled landfills (Danish EPA, 2001c).

During the course of 1997-98, a number of private firms have also worked to establish alternative sludge-disposal methods in which the inorganic fraction (the ash) is reused in such products as cement and sand-blasting agents.

Samples representative of about 94.5% of the dry matter content of sludge were studied in 1999, with a view to determining their content of mercury and other heavy metals (Danish EPA, 2001c). The weighted average for mercury was about 1,200 mg/tonne and, on the assumption that the studied sludge was representative of the total quantity of collected sludge, the total quantity of mercury in sludge can be estimated at 150-230 kg/year. The distribution of this over the various types of disposal method is shown in Table 3.10.

In comparison to 1994, when the circulation of mercury in sludge was estimated at about 250 kg in 170,000 tonnes of dry matter, it can be seen that there is a possible trend towards a drop in the total circulation of mercury.

Agricultural soil, forests, and market gardens received a total of 62-94 kg of mercury in sludge. A small part of this sludge was treated in biogas plants or composting plants before its application to soil.

Part of wastewater sludge is disposed of by incineration - either externally or internally, at the individual sewage treatment plant. The incinerator plant is fully equipped with flue gas cleaning equipment. The emission factor for mercury at Danish incinerator plants is roughly estimated at 50-70%. Against this background, the total emission resulting from the incineration of sludge can be estimated at 25-50 kg of mercury/year, whereas any other mercury content of the sludge is deposited together with the residual products.

Table 3.10
Mercury in wastewater sludge, distributed by final disposal (based on Danish EPA, 2001c)

Final disposal	Sludge,	Total mercury content	
	tonnes of dry matter/year x 1000	kg Hg/year	Percentage of total
Agriculture, etc. 1)	86	62-94	41
Incinerated 2) 3)	35	43-65	28
Landfilled 2)	5.9	7.2-11	5
Long-term storage 2)	9.1	11-17	7
Miscellaneous 2)	23	28-42	18
Total (rounded)	160	150-230	100

Notes:
1) The average mercury content of sludge applied to agricultural soil or in forests, etc., is stated to be 910 mg/tonne of dry matter. This average value is considered to have been determined with considerable certainty because of the large number of samples taken.
2) The average mercury content of sludge that is not applied to agricultural soil can be estimated at 1,530 tonnes/year on the basis of Danish EPA 2001c. This value is considered to have been determined with relatively high certainty. No specific values are quoted for sludge deposited in landfills, incinerated, etc. We assume that the average mercury concentration has remained roughly the same for each of these types of disposal.
3) Of this, about 21.5-46 kg of mercury/year is emitted to air.

3.5 Summary of mercury losses in waste treatment

The available information on the loss of mercury in connection with the circulation of waste products is summarised in Table 3.11.

Table 3.11
Losses of mercury in the management of waste products in Denmark, 2001 (kg/yr of mercury)

Product/application	Estimated disposal and losses (kg/yr Hg) to:				
	Air	Water	Soil	Deposition	Miscellaneous
Management of scrap	40-60	-	-	180-220	
Production of iron and steel	0.5	-	-	52	310 2)
Waste incineration	270-1,000	-	-	2,000-2,900 5)	-
Deposition (excl. residual products of incineration)	-	2.5 1)	-	120-480 6)	-
Biological waste treatment	-	-	30-49	-	-
Oil and chemical waste/hazardous waste	6-13	0.14	-	7.6	2,000-3,900 3)
Discharges from municipal waste treatment plants	-	14-280	-	-	-
Storm water discharges	-	41	-	-	-
Miscellaneous wastewater	-	13-40	-	-	-
Wastewater sludge	20-50	-	60-90	40-47	30-40 4)
Total (rounded)	340-1,100	40-360	90-140	2,400-3,700	2,300-4,300

1) Percolate from landfills is piped to municipal waste treatment plants.
2) Iron and steel for recovery.
3) Mercury-containing waste, which is exported.
4) Wastewater sludge, which is not exported but is temporarily stored.
5) By far the greater part of this is exported for deposition in Norway and Germany.
6) See Table 3.4

4 Overall assessment

4.1 Applications and consumption in Denmark

The available information and estimates of mercury consumption in Denmark, 2001, are summarised in Table 4.1.

Table 4.1
Mercury consumption in Denmark, 2001

Product group	Consumption, kg Hg/year	Percentage of total	Development trend
Metallic mercury			
Dental fillings	1,100-1,300	34	Stagnating/falling
Light sources	59-170	3.2	Falling
Switches, contacts and relays	0-24	0.34	Falling
Clinical thermometers	1.1	<0.1	Falling
Other thermometers	15-23	0.54	Falling
Monitoring equipment	12-48	0.85	Falling
Other uses as a metal	35-60	1.3	Stagnating
Chemical compounds			
Mercury-containing batteries	0.5-0.6	<0.1	Falling
Other batteries	70-150	3.1	Falling
Laboratory chemicals	30-70	1.4	Falling
Medical applications	0-1	<0.1	Falling
Other chemical applications	5-50	0.77	Falling
As impurity			
Coal	600-1,000	23	Falling
Oil products	2-30	0.45	Stagnating
Natural gas	0.4-3	<0.1	Stagnating
Drilling mud	-	<0.1	Stagnating
Biological fuels	18-76	1.3	Rising
Cement	26-65	1.3	Stagnating
Fertiliser and feeding stuffs	11-36	0.66	Stagnating
Agricultural lime	-4.4	<0.1	Falling
Foodstuffs	9.6-17	0.37	Stagnating
All other goods	90-1,900	28	Various
Total (rounded)	2,100-5,000 1)	100	

1) In the summation, mercury in fly ash was subtracted, as this ash is used in cement production and thus occurs twice in the table.

As is apparent from Tables 4.1 and 4.2, the current consumption of mercury can be estimated as follows:

Intentional uses (rounded)	about 1,320-1,900
Uses as an impurity	about 740-3,100
Total (rounded)	about 2,100-5,000

Thus, intentional uses are responsible for about half of the total consumption, of which dental fillings alone account for 1/3. For the sake of comparison, Table 4.2 also shows the consumption in 1992-93 and 1982-83.

Development trends, consumption

Table 4.2
Mercury consumption in Denmark for 1982-83, 1992-93 and 2001

Product group	1982/83 kg Hg/year	1992/93 kg Hg/year	2000/01 kg Hg/year
Metallic mercury			
Dental fillings	3,100	1,800	1,100-1,300
Light sources	140	170	60-170
Switches, contacts and relays	160-520	200-400	0-20
Clinical thermometers	750	50	1.1
Other thermometers	1,300-1,800	100	15-20
Monitoring equipment	430-630	500	10-50
Chloro-alkali production	3,000	2,500	-
Other uses as a metal	-	-	40-60
Chemical compounds			
Mercury-containing batteries	2,400	280-430	0.5-0.6
Other batteries	2,300	120-430	70-150
Laboratory chemicals	500	60-120	30-70
Medical applications	-	-	0-1
Other chemical applications	1,050-1,900	<50	5-50
Total, intentional uses	15,100-17,000	5,800-6,600	1,300-1,900
As impurity			
Coal	1,000-2,000	500-1,300	600-1,000
Oil products	<50	2-34	2-30
Natural gas	-	-	0.4-3
Biological fuels	-	30-45	18-80
Cement	10-80	60-220	30-70
Agricultural lime, fertiliser and feeding stuffs	20-130	<50	11-40
Foodstuffs	-	<50	10-20

All other goods	30-600	70-1,400	94-1,900
Total, impurities	1,100-2,900	660-3,100	760-3,100
Total (rounded)	16,200-19,900	6,400-9,600	2,100-5,000

There has been a sharp drop in the consumption of mercury over the past 20 years, see Table 4.3.

Table 4.3
Trend in average mercury consumption in Denmark since 1982/83

	1982-83		1992-93		2001	
	(kg Hg/year)		(kg Hg/year)		(kg Hg/year)	
Total	18,050	100%	8,000	44%	3,550	20%
Intentional uses	16,050	100%	6,200	39%	1,600	10%

Despite the drop in consumption in most of the intentional uses, it is worth noting that, logically enough, applications in which consumption was high in earlier years, and which are strictly regulated at the national and international levels, have become more peripheral. Instead, applications are now gaining prominence that have not been exposed to the same regulatory pressure, and perhaps for this reason have not been developed to the same extent in recent decades. This still applies, for instance, to dental fillings, to button cells of types other than mercuric oxide and to light sources.

It is also worth noting that the mobilisation and release of mercury as a trace element in coal is still falling, primarily because of the endeavour to shift energy production away from coal in Denmark in order to reduce the emission of carbon dioxide and a number of other pollutants.

Mercury as an impurity in “All other goods” was assessed as being low in 1982-83. This is because a different assessment method was used at that time and it is therefore not an expression of a trend. There is no basis for expecting any real difference between 1982-83 and the other years. The large interval reflects the fact that, in all cases, this type of consumption can only be estimated with considerable uncertainty.

4.2 Releases to the environment in Denmark

The available information and assessments of releases of mercury to the environment in Denmark are summarised in Table 4.4. As can be seen from the table, total releases in 2001 can be estimated at:

to air:	820-2,000	kg/yr
to water:	50-460	kg/yr
to soil:	170-270	kg/yr

In addition, about 2,700-4,400 kg/year is deposited, e.g., in roads, dams, and other structures in which residual products of waste incineration and coal combustion are used.

Emissions to air
The main causes of emissions to air are:

waste incineration:	about 45% of all emissions
coal combustion:	about 18% of all emissions.

The remaining emissions are chiefly due to cement production, other forms of waste management and cremations. It should be noted that industrial processes only appear to be responsible for about 9% of all emissions in Denmark.

In addition, it should be noted that the mercury content of combustible waste must primarily be attributed to mercury as an impurity (about 30%), batteries (about 22%) and switches, contacts and relays (about 18%), cf. Table 3.4. The contribution from batteries, switches, contacts and relays must to a considerable extent be assumed to depend on earlier consumption, which is only slowly disposed of before it finally ends in waste.

Emissions of mercury to air have dropped to about 1/4 of the level of 1982-83. This is particularly due to a drop in the emissions from waste incineration, which again is due to improved flue gas cleaning. Emissions in 2001 amounted to less than 2/3 of those in 1992-93. This drop is linked to a drop in emissions from the production of iron and steel, from coal combustion and from the disposal of light sources.

Discharges to water
Discharges to water are primarily dependent on the mercury in wastewater, which chiefly consists of mercury from dental clinics (more than 60%), but also, e.g., from thermometers and monitoring equipment, cf. Table 3.8.

Discharges to water have fallen to about 18% of the 1982-83 level, but remain at the 1992-93 level - or perhaps a little higher. The latter conceals the fact that discharges to the marine environment from offshore oil and gas extraction are included in the account for 2001.

Releases to soil
Releases of mercury to soil mainly depend on:

wastewater sludge:	about 35% of all releases
burials:	about 32% of all releases
fertiliser and feeding stuffs:	about 11% of all releases.

Releases to soil remain at the level of the previous mass flow analysis, but are significantly lower than losses to soil in 1982-83; this change is due to the fact that the practice of dressing seed corn has been discontinued.

Releases to deposition

The greater part (80%) of the mercury deposited comes from the residual products of waste incineration.

The deposition in landfills of mercury has increased since the earlier accounts. This is related to the efficiency of flue gas cleaning, which to some extent removes mercury from smoke, so that emissions to air are reduced, although the mercury is still to be found in the residual products of waste incineration; at the same time, the quantity of waste that is incinerated has increased. By far the greater part of the residual products of waste incineration is deposited outside Denmark (in Norway and Germany).

Total release
Thus, the total release of mercury only shows a small drop since the previous mass flow analysis. The uncertainty interval has however increased, especially because of the uncertainty concerning mercury in residual products, which constitutes the greatest loss of mercury to the environment.

Uncertainty
This account of the disposal and losses of mercury is to some extent based on estimates with inherent uncertainties, which will always be open to discussion.

The quantities estimated to have been sent to waste incinerator plants appear to be too low in relation to the recorded quantities. This could be related to the fact that the mercury content of products is falling sharply. This makes estimation of the disposal and loss quantities extremely sensitive to the life-cycles and "box-room" effect applied in calculations involving mercury-containing products. The box-room effect is an expression of the fact that, when products are worn out they are stored by consumers for some period before they are disposed of. On the basis of the available information, it is not possible to determine whether the input sources have in fact been underestimated or whether it is a question of general uncertainty in the calculations.

Bearing this reservation in mind, the accuracy of the estimated disposal and loss quantities can in summary be characterised by the fact that the orders of magnitude of the stated quantities can be considered reliable.

Table 4.4
Releases of mercury to the environment in Denmark, 2001

Product/application	Estimated loss (kg mercury) to:				
	Air	Water	Soil	Deposition	Total (rounded)
Industrial processes					
Cement production	70-170	-	-	-	70-170
Production of iron and steel	0.5	-	-	52	53
Manufacture and repair of light sources	-	-	-	-	-
Oil and gas extraction	0.2-11	4-86	0.3-10	-	4.7-110
Energy production					
Coal	190-310	-	-	68-110 3)	260-420
Oil	6-46	5-7	-	6-13 3)	17-66
Natural gas	1-4	-	-	-	1-4
Biological fuels	14-61	-	1-5	2-10 3)	18-76

Use of products					
Dental clinics	-	50-250 1)	-	-	50-250 1)
Thermometers	-	20-40 1)	-	-	20-40 1
Monitoring equipment	20-50	20-50 1)	-	-	40-100 1)
Laboratories	-	-	-	-	-
Fertiliser and feeding stuffs	-	-	11-36	-	11-36
Agricultural lime	-	-	2-4.4	-	2-4.4
Lighthouses	5-10	-	-	-	5-10
Waste management					
Disposal of light sources	1-9	-	-	-	1-9
Collection of metallic mercury	-	-	-	-	-
Other recycling activities	-	-	-	-	- 1)
Waste incineration	270-1,000	-	-	2,000-2,900 2)	2,300-3,900
Biological waste treatment	-	-	30-49	-	30-49
Deposition (excl. residual products of incineration)	-	2.5	-	120-480 4)	120-480
	6-13	0.14	-	7.6	14-21
Discharges from municipal sewage treatment plants	-	14-280	-	-	14-280
Other discharges of wastewater	-	20-80	-	-	20-80
Wastewater sludge	20-46	-	62-94	40-47	120-190
Scrap management	40-60	-	-	180-220	220-280
Other activities					
Cremations/burials	170-190	-	67-75	-	240-270
Total (rounded)	820-2,000	50-460	170-270	2,400-3,700	3,500-6,500

1) The stated quantities are discharged to wastewater where, after treatment in sewage treatment plants, the mercury will end in the sludge and water discharged by the plant. These quantities are therefore included under "Discharged from municipal sewage treatment plants" and "Wastewater sludge," and are not included again under "Total."
2) Deposited abroad.
3) Included in "Deposition (excl. residual products of incineration)."
4) See Table 3.4.

Releases to deposition and air from waste incinerator plants are primarily due to dental amalgam, batteries, light sources and switches, contacts and relays.

Table 4.5
Releases of mercury to the environment in Denmark, 1992-93

Product/application	Estimated loss (kg mercury/year) to:				
1992/93	Air	Water	Soil	Deposition	Total (rounded)
Industrial processes					
Electrolysis	<6	<1	-	-	7
Cement production	60-220	-	-	-	60-220
Production of iron and steel	70	-	-	-	70
Manufacture and repair of light sources	5-10	-	-	-	5-10
Energy production					
Coal	200-500	-	3-9	150-500	350-1,000
Oil	2-34	-	-	-	2-34
Natural gas	-	-	-	-	-
Biological fuels	15-25	-	-	15-20	30-45
Use of products					
Dental clinics	-	150-200 1)	-	-	150-200 1)
Thermometers	-	100-250 1)	-	-	100-250 1)
Monitoring equipment	-	<100 1)	-	-	100 1)

Laboratories	-	<10 1)	-	-	10 1)
Fertiliser and agricultural lime	-	-	<100	-	50-100
Miscellaneous	2.5	-	-	-	2.5
Waste management					
Disposal of light sources	120-140	-	-	-	120-140
Collection of metallic mercury	50	-	-	-	50
Other recycling activities	<50	-	?	130 3)	130-180 2)
Waste incineration	1,100	-	-	1,300	2,400
Biological waste treatment	-	-	1	-	1
Deposition (excl. residual products)	-	2.5	-	400-1,100	400-1,100
Oil and chemical waste/hazardous waste	110	-	-	400-1,600	510-1,700
Discharged from municipal sewage treatment plants	-	250	-	-	250
Wastewater sludge	50	-	140	60 3)	250 2)
Other activities					
Cremations/burials	100	-	50	-	150
Total (rounded)	1,880-2,470	250	200-300	2,300-4,500	4,600-7,500

1) The stated quantities are already included under "Discharged from municipal sewage treatment plants" and "Wastewater sludge."
2) The stated quantities are only summated in the event that they are not included under other headings.
3) The stated quantities are already included under "Deposition (excl. residual products)" and are therefore not included under "Deposition, total".

Table 4.6
Releases of mercury to the environment in Denmark, 1982-83

Product/application	Estimated loss (kg mercury/year) to:				
1982/83	Air	Water	Soil	Deposition	Total (rounded)
Industrial processes					
Electrolysis	20	40	-	-	60
Cement production	160-380	-	-	-	160-380
District heating power plants	-	50 1)	-	-	50 1)
Purification of mercury	100-150	-	-	-	100-150
Fertiliser production and other industrial processes	-	20-50	-	-	20-50
Energy production					
Coal	500-1,000	?	?	230-450	730-1,500
Oil	40	-	-	20	60
Use of products					
Dental clinics	-	600-1,100 1)	-	-	600-1,100 1)
Thermometers, monitoring equipment	<250	200-450 1)	-	-	200-700 2)
Laboratories	100	40-90 1)	-	-	140-190 2)
Fertiliser and agricultural lime	-	-	20-130	-	20-130
Dressed seed corn	-	-	800-890	-	800-890
Waste management					
Disposal of light sources	140	-	-	-	140
Collection of metallic mercury	100	-	-	-	100
Other recycling activities	70-200	-	30-100	-	100-300
Waste incineration	2,300-3,900	-	-	200-300	2,500-4,200
Deposition of solid waste	-	<20	5	1,000-1,800	1,000-1,800
Chemical waste/Kommunekemi	20-40	-	-	30	50-70

Discharged from municipal sewage treatment plants	-	1,300	100	-	1,400
Wastewater sludge	280	-	240	280	800
Other activities					
Cremations/burials	270	-	180	-	450
Total (rounded)	4,100-6,900	1,400	1,400-1,600	1,700-2,900	8,500-12,800

1) The stated quantities are included under municipal wastewater.
2) Partly counted under municipal wastewater.

4.3 Mercury balance for Denmark

The available information and estimates of the consumption and losses of mercury to the environment in Denmark are illustrated in Fig. 4.1. Concerning the figure, the following should be born in mind:

The net importation of mercury is not known precisely, but is estimated on the basis of the available calculation of the consumption of mercury in Denmark.

In contrast to the previous mass flow analysis, no significant exports of mercury-containing products have been found. Exports during 1992-93 included 600-700 kg of mercury, which included batteries, thermometers, and flashing lights for controlling rail traffic. Danish battery manufacturers only produce alkaline batteries that are not button cells. The mercury content of such batteries amounts to a maximum of 15 kg (see Section 2.3.1). Mercury-containing thermometers are no longer manufactured in Denmark. Danish consumption of mercury in flashing lights has dropped, from about 10 kg in 1992-93, to about 0.2 kg in 2001. A corresponding drop probably also applies to exports of these, which in 1992-93 amounted to 90 kg of mercury. In summary, the export of mercury in products and semi-manufactured goods is estimated at less than 50 kg/year.

Part of the consumption of mercury as an impurity is due to the recycling of products, and a lesser part, to the consumption of Danish agricultural lime and biological fuels. Net imports of mercury are calculated as the total consumption of mercury as an impurity minus the part of this consumption that results from the recycling of products and from Danish agricultural lime and biological fuels.

Recycling covers the recirculation of mercury as an impurity in recycled material.

Overall, the above imports and recirculation correspond to the stated consumption of 2,100-5,000 kg of mercury/year.

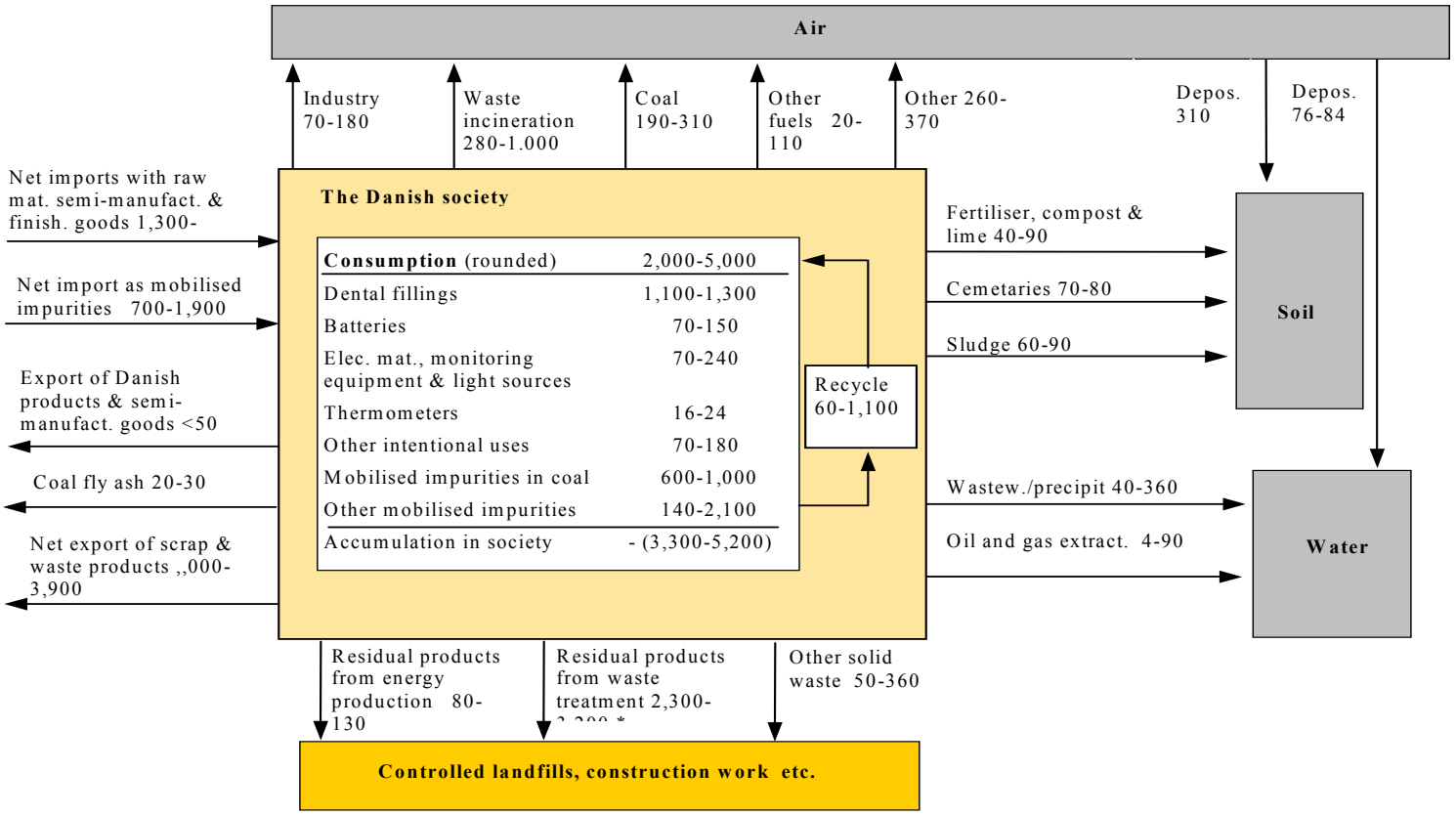
The corresponding figure in the previous mass flow analysis featured a special box for Kommunekemi. Today, Kommunekemi is just one actor of several who handle mercury-containing waste. These actors send all of their mercury-containing waste abroad - possibly after sorting. The only mercury-containing waste that is treated in Denmark consists of amalgam filters, which are cleaned for reuse, and straight fluorescent tubes, the powder of which (containing mercury) is separated and exported. The loss of mercury to the environment due to these activities is small and is included under "Miscellaneous to air" in Fig. 4.1.

There is no longer any true collection of metallic mercury as there was in 1992-93. Metallic mercury is collected with other mercury-containing waste and exported. The figure shows metallic mercury under "Scrap and waste products."

By far the greatest part of mercury emitted to air by industry is due to cement production. There is also a minor contribution from offshore oil and gas extraction. Mercury from cremations constitutes 170-190 kg of "Miscellaneous to air."

The estimate given for the precipitation from air has been taken from Kjølholt et al., 1998, and represents the background precipitation, i.e., the atmospheric precipitation at points remote from the point sources. Mercury evaporates from agricultural soil and from water surfaces. No attempt has been made to estimate the magnitude of these transports.

Fig. 4.1
Mercury balance for Denmark, 2001 (all figures in kg/year)



*Of this, 1,900-2,900 kg of mercury is exported for deposition abroad.

Accumulation in Denmark
As can be seen from the figure, it is possible to calculate a negative accumulation of mercury of between 3,300 and 5,200 kg in Denmark. This illustrates the drop in

mercury consumption, as well as the fact that existing stocks of mercury in Denmark are becoming depleted.

The total stock of mercury in Denmark in 1992-93 was estimated at 50-250 tonnes. In 1992-93, the negative accumulation amounted to between -(3,100 and 7,900) kg. The total depletion of the stock in the period up to 2001 is not known with any certainty, but it probably amounted to about 40 tonnes.

Airborne imports/exports
As can be seen from the figure, the air in Denmark must be expected to receive an annual 820-2,000 kg of mercury, whereas the background precipitation on Danish agricultural soil and in Danish coastal waters constitutes an annual total of 390 kg of mercury. In addition, there is the evaporation from agricultural soil and from inner Danish coastal waters. With reservation for the uncertainty introduced by the fact that there is no data for the expected, increased, precipitation in urban areas and close to the point sources of mercury emissions, Denmark must be expected to be a net exporter of atmospheric mercury. This was also the case in 1992-93 (Maag et al., 1996), even though the release and precipitation values have fallen since then.

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Appendix 1:Reported numbers of dental fillings and numbers of tooth extractions

Reported number of dental fillings and number of tooth extractions, source: Association of County Authorities in Denmark.

Year	1994	1995	1996	1997	1998	1999	2000	2001
"a" fillings	548,532	452,155	400,240	?	378,493	340,535	300,567	274,272
"b" fillings	772,085	739,742	717,497	?	700,957	674,372	620,838	576,289
"c" fillings	362,135	335,360	303,901	?	289,547	277,939	279,000	259,627
Sum	1,682,752	1,527,257	1,421,638	?	1,368,997	1,292,846	1,200,405	1,110,18
Tooth extractions	350,677	356,425	364,695	?	365,015	363,106	352,755	354,519

Appendix 2: Firms consulted during the course of this mass flow analysis

Affaldscenter Århus, Århus Amagerforbrænding I/S, Copenhagen S
Amtsrådsforeningen AV Miljø, Hvidovre Averhoff Genbrug A/S, Århus AVV, Hjørring
Banestyrelsen, København Basta
Danmark A/S, Korsør
Batteriforeningen, Copenhagen K
Bedemændenes landsforening
Bendix Neon ApS., Viborg Bie &
Berntsen A-S, Rødovre Bilka
Indkøb A/S, Tilst Bombardier
Bosch, Ballerup
Brancheforeningen for Høreapparater i Danmark
BR-Legetøj A/S, Top Toy, Roskilde Canon
Danmark, Søborg Canon Europe, Holland
Center for Restprodukter, Hørsholm
Cheminova, Lemvig Cirring Dental
ApS COOP Danmark, Albertslund
COWI, Lyngby
D34 Dental Aktieselskab af 1934, Rødovre
Daconet A/S, Skive
Dandental
Dankalk, Løgstør
Danmarks Apotekerforening
Dansk Autogenbrug, Copenhagen
Dansk Gasteknisk Center DGC, Hørsholm
Dansk Genvinding A/S, Trige Dansk
Nordenta
Dansk Olie Genbrug A/S, Kalundborg
Dansk RestproduktHåndtering, DRH, Odense
Dansk Specialaffald AS, Copenhagen S (Amager)
Dansk Tandlægeforening, Copenhagen K.
Danske Fjernvarmeværkers Forening, Kolding
Dental-Partner Produktion ApS, Egå Den-tec A/S, Virum
Det Danske Stålvalseværk, Frederiksværk
DONG, Hørsholm
DONG, Nybro, laboratoriet
ELEKTRO MILJØ A/S, Vejle Elektroluma, Søborg
ELSAM, Fredericia
El-Supply, Nexø
ENERGI E2 A/S, Ballerup
Energistyrelsen, 7. kontor
EnviDan A/S, Silkeborg
Esbjerg Havn, Esbjerg
Eurocenter under Erhvervsfremmestyrelsen

FDM
Grundfos, Bjerringbro
Gunnar Lund Olieservice A/S, Esbjerg
H. J. Hansen Genvindingsindustri A/S, Odense
Hadsund Bys fjernvarmeværk, Hadsund Haldor
Topsøe A/S, Lyngby Hals Metalindustri A/S, Hals Hintze Holm APS
Hirtshals Havn, Hirtshals
Horsens Kraftvarmeværk, Horsens
Huch & Holm, Herlev
Ib Due's Guldvarefabrik I/S, Århus
IT og Telestyrelsen
Institut for Elektroniske Systemer, AUC
K.E. Mathiasen A/S, Brabrand KARA I/S (Roskilde), Roskilde Lundbeck, Valby
Kemira Danmark A/S, Fredericia
Kommunekemi a/s, Nyborg
Metaligen International ApS, Ringsted
Miljøfirmaet Pap & Plast A/S, Randers
Mærsk Olie og Gas A/S Nettodental, Risskov Nicha Miljøteknik A/S, Vissenbjerg
NKT Cables A/S, Stenlille
Nomeco
Odense Kraftvarmeanlæg (ELSAM)
Phillips
Piesens Fiskeriartikler, Fjerritslev
Plantedirektoratet, Lyngby
RAMBØLL, Virum Randers Reb A/S, Randers Rasch Dental, Smørum Rectus ApS, Viby J RenoFlex, Copenhagen S, Reno-Nord I/S, Aalborg ReturBat, København RGS 90 A/S, Copenhagen
RS Components A/S, Copenhagen NV
Ry Fotohandel
Ry Kommunale Tandpleje, Ry
Ry Kommune
SAYBOLT DANMARK A/S, Copenhagen S
Scandinavian Calcium Oxide ApS, Løgstør
Scanfors A/S, Risskov Shell Raffinaderiet, Fredericia Shell, Kalundborg
Sigma-Aldrich, Vallensbæk
SMC
Special Waste System A/S, Nr. Alslev
Statens Seruminstitut, Kbh. S Statoil, Kalundborg, København Studstrupværket, ELSAM, Skødstrup Søren Lindstrøm, tandlæge, Vejle Tandlægehøjskolen, Panuminstituttet i Kbh. Tandlægeskolen i Århus
TDC A/S, Tranbjerg
Tech-wise A/S, Fredericia
Thyborøn Havn, Thyborøn
Thyborøn Trawlbinderi A/S, Thyborøn Uniscrap A/S Genvindingsindustri, Kolding Uniscrap A/S Hasselager, VEGA I/S, Taastrup
Vejen Kraftvarmeværk A/S, Vejen
Vestforbrænding I/S, Glostrup
Videncenter for Halm & Træflisfyring, ved Dansk Teknologisk Institut, Teknologiparken, 8000 Århus C
VN Legetøj A/S, Hasselager

Vrist-Cut, Harboøre
VWR International (tidl. Struers Kebolab), Albertslund
Østjydsk Dantal-Teknik ApS, Vejle Aadum Autoophug
Aalborg Portland A/S, Aalborg