MERCURY IN DENTAL USE:
ENVIRONMENTAL IMPLICATIONS FOR THE EUROPEAN UNION

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Executive Summary

Background and scope

The use of mercury in dental tooth fillings comprises some 30% of the annual mercury consumption in the EU. However, the diffusion of much of this mercury into the environment is not widely appreciated, and there is growing public concern about the use of mercury in the medical arena. Considering that there are wide differences among EU Member States in dealing with these issues, a closer investigation is therefore warranted.

The traditional so-called “silver fillings” used to fill dental cavities contain approximately 50% mercury. In a number of scientific studies health effects have been observed, although the effects of exposure from mercury amalgam on human health continue to be debated. This paper has chosen not to address direct effects on human health – not because that debate is unimportant, but because the environmental effects (and indirect health effects via diet) related to the dental use of mercury are already clearly evident, widespread, costly and mostly avoidable.

Mercury and its compounds are highly toxic to humans, ecosystems and wildlife. High doses can be fatal to humans, but even relatively low doses can have serious adverse neurodevelopmental impacts, particularly on the developing fetus and children. They have also recently been linked with possible harmful effects on the cardiovascular, immune and reproductive systems. Methylmercury collects and concentrates especially in the aquatic food chain, making populations with a high intake of fish and seafood particularly vulnerable.

One of the major findings of this report is that EU mercury amalgam wastes significantly increase the load of mercury to both the local and global environment. Further, mercury from dental amalgam is known to be transformed into methylmercury. To the extent EU dental mercury is responsible for increases in human exposure to methylmercury through fish in the diet, then appropriate measures must be taken.

In broad terms, the scope of this paper may be described as:

- Focusing on the contributions, mass balance and flows of dental mercury through the EU environment;
- Briefly summarising legislation and policies dealing with these flows; and
- Making specific observations with regard to the management of dental wastes, and the use of mercury in dentistry.

Environmental pathways and mass balance

The “mass balance” analysis – matching mercury inputs with outputs – has concentrated mostly on the series of activities that take place in the dental clinic, and the “downstream” flows of mercury from there. In other words, it includes amalgam waste generated prior to the placement of a filling; the excess material carved from new amalgam fillings; the removal of old amalgam fillings; the removal of teeth containing amalgam; other mercury going to solid waste or wastewater; mercury emissions directly to the air; the traps, filters and other devices
in dental clinics to remove mercury from the wastewater; and various waste disposal alternatives.

Mercury can enter the environment from a number of pathways. For example, if a mercury-containing item is discarded in municipal waste, the mercury may be released into the atmosphere from landfill vapours or leachate, or the mercury will vaporize if the waste is incinerated. If mercury is flushed through a wastewater system, the mercury will likely adhere to wastewater sludge, which may be incinerated, instantly releasing the mercury vapour to the air. Or if the mercury-laden sludge is deposited to agricultural or other soil, it may volatilize or be carried away in runoff. Whatever mercury enters the atmosphere through these various means will travel through the atmosphere in a vaporized state before eventual deposition, etc. Unfortunately, mercury fillings continue to pose a pollution problem even after death. About two-thirds of mercury in these fillings ends up in a cemetery, from where the mercury eventually enters the soil and/or groundwater, while most of the rest is emitted to the atmosphere during cremation – and the rate of cremations is increasing across the EU.

Starting from a “human inventory” of EU dental mercury estimated at some 1100 tonnes, this analysis has developed a model of EU dental mercury flow pathways and quantities as presented in the summary figure here for one year. In general terms this diagram shows 109 tonnes (rounded) of mercury releases from ongoing dental practices, plus another 14 tonnes of mercury in the teeth of deceased persons – for a total of some 123 tonnes – directly entering the EU waste stream annually.

Of this total waste stream, approximately 46 tonnes is thought to be removed from circulation and not released to the environment (of which 22 tonnes appear to be recycled and returned to commerce). The remaining approximately 77 tonnes likely ends up in various environmental media, chiefly the soil (30 tonnes) and atmosphere (23 tonnes). In addition, important amounts are released to surface waters (14 tonnes) and groundwater (10 tonnes). In these environmental media the mercury may be expected to continuously circulate in the biosphere, partially methylate, enter the food chain and detrimentally affect wildlife and human health.

### Bioavailability

There has been some debate concerning the ability of dental mercury to become “bioavailable” in the environment. However, scientific research has confirmed the transformation of dental mercury into methylmercury in the mouth, in dental and municipal...
wastewater systems and in sewage treatment plants. Laboratory research has further confirmed that dental amalgam particles themselves release mercury into the surrounding water in a form that can and does accumulate in fish.

**Cost of dental mercury**

While most dental professionals who place mercury amalgams typically charge somewhat less for amalgams than for the alternatives, the full costs borne by the rest of society are much higher after taking into account the overall environmental health ramifications. Once dental mercury has been used, there are a number of “end-of-pipe” techniques to keep it from entering the environment, but each of these techniques comes at a (sometimes very high) cost, and may not be as effective as hoped. Further, the broad diffusion of “end-of-pipe” techniques throughout the EU cannot be taken for granted. Since it is internationally agreed that the global pool of mercury circulating in the biosphere needs to be greatly reduced, society’s choice is straightforward – either we are obliged to pay such costs to ensure that mercury does not eventually enter the environment, or we must take the alternative path of preventing mercury from being used in the first place.

**Regulations**

There are various types of legislation and related measures that are designed to address the different aspects of mercury released from dental applications. These measures all attempt to keep mercury out of the environment, and typically fall within three categories:

1. Sweden, Denmark, Germany (for the more sensitive population groups) and Norway have taken formal or informal measures with the objective of eliminating the use of mercury, which have the effect of reducing mercury through the whole life cycle, including dental releases, crematoria releases, and the global pool of mercury circulating in the biosphere.

2. Measures may be adopted by dental practices with the objective of reducing their releases of mercury, such as capture and sequestration of as much mercury as possible, and then hazardous waste disposal or possibly recycling. The EU (as other countries) considers mercury amalgam waste as hazardous waste, and effectively requires the use of separators to remove mercury from the wastewater of dental clinics.

3. OSPAR has called for measures to be adopted by crematoria with the objective of reducing their mercury releases, especially recommending the use of flue gas controls. Based on a 2006 OSPAR report it is evident that over 80% of the nearly 1000 crematoria in the EU-27 have no or limited emission controls.

**Observations**

*What is the magnitude of mercury use in dental amalgam?*

Dental use is the second largest use of mercury in the EU-27, behind the use of mercury in the chlor-alkali industry, which is under heavy pressure to become mercury-free. It is estimated that EU dental professionals use some 125 metric tonnes of mercury, and place over 200 million mercury fillings each year, while the EU population as a whole carries over 1100 tonnes of mercury in their mouths.
**What is the magnitude of mercury releases due to dental amalgam?**

In terms of mercury emissions to the atmosphere, emissions related to dental use may well exceed 20 tonnes/year – exceeded in the EU only by coal combustion and chlor-alkali plants (Maxson 2006b). Estimated releases to surface waters of 10-20 tonnes would put dental applications solidly in first place in this category. And with a further 30-50 tonnes released to the groundwater and the soil, dental uses appear to be in close competition with chlor-alkali plants (Maxson 2006b) for first place in the EU in terms of total mercury released to the environment.

**What is the environmental problem of mercury in dental amalgam?**

Entirely apart from any question of health effects due to inhalation of mercury vapour from fillings, the use of mercury in dental amalgam is not a controlled use of mercury, despite increasing efforts to implement end-of-pipe emission reduction measures. It is a use that clearly leads to significant dispersal of mercury throughout the environment via wastewater, sewage sludge disposal to land, solid waste incineration, cremation, etc. Furthermore, it has been demonstrated that a certain portion of this mercury becomes bioavailable, and may constitute a significant source of risk to human health and the environment. Dental use of mercury is a major contributor to the global pool of mercury circulating in the environment, which the EU, in its Community Strategy on Mercury, has determined needs to be urgently reduced.

**What is the real cost of mercury in dentistry?**

Especially in light of the wide dispersal of dental mercury in the environment, end-of-pipe mercury removal and environmental cleanup solutions are always far more expensive than preventing releases in the first place. The EU has accepted that it needs to better manage the risk of environmental and health effects due to mercury. Such mercury control and cleanup costs are one indicator of the real costs to society of continued use of mercury in dental fillings.

**Do cost-effective solutions exist?**

Without doubt the most cost-effective and environmentally responsible solution to the dental mercury problem is rapidly phasing out mercury in dental use, for which there are a range of affordable mercury-free alternatives. The number of dental restorations for which dental professionals might argue that a mercury amalgam is the only viable option are very few in number. For example, in Sweden mercury amalgam is currently used for less than five percent of fillings, clearly demonstrating the viability of mercury-free alternatives.

**What are the main barriers to a phase-out of mercury amalgams?**

There is evidence that less than one-third of the general public is aware that mercury is the main component of “silver” fillings, and patients are often not aware of alternative filling materials. The dental profession, the general public and policy-makers are not well informed about the full costs to society of continued use of mercury in dentistry, its dispersal in the environment, the human health and environmental implications, and the viability of alternative filling materials. As a general rule, EU Member States continue to offer subsidies of mercury amalgams through healthcare system reimbursements, which reinforces their continued use; they do not adequately manage hazardous dental amalgam wastes, which leads to unnecessary releases to various media; and they have not effectively implemented controls on mercury emissions from crematoria, which leads to unnecessary atmospheric releases. The diverse and serious environmental problems related to mercury in amalgams would be greatly reduced if, in their oversight role, European agencies were to engage in a more focused effort to encourage Member States to phase out mercury amalgams altogether.
Mercury in dental use:
Environmental implications for the European Union

1 Introduction

1.1 Scope

Considering the growing public interest in the use of mercury in dental tooth fillings, and the wide differences among EU Member States with regard to this practice, a closer investigation is critical. The traditional “silver fillings” used to fill dental cavities contain around 50% mercury and are the largest source of elemental mercury exposure in people who have fillings (European Commission 2005). There is evidence that hot foods and liquids, as well as normal chewing, release mercury vapours from fillings (Mutter et al. 2004). In a number of scientific studies health effects have been observed (Mutter et al. 2004), although the effects of exposure on human health continue to be debated. Nevertheless, some countries are taking concrete steps to reduce the use of mercury in dentistry.

This paper has chosen not to address the possible direct effects of mercury amalgam on human health – not because that debate is unimportant, but because the environmental effects (and indirect health effects via diet) related to the dental use of mercury are already clearly evident, widespread, costly and entirely avoidable. Dental mercury has long been recognised as a significant source of mercury releases to the environment. Nevertheless, in Europe there has been relatively little effort devoted to compiling a detailed picture of the pathways followed by such releases, and the potential bioavailability of various mercury releases.

The European Commission has acknowledged that dental amalgam wastes are among the largest sources of mercury in municipal wastewater – some of which eventually make their way to fish and humans in the form of methylmercury. In response, the Commission listed the following action, among others, in its Community Strategy on Mercury (European Commission 2005):

**Action 4.** The Commission will review in 2005 Member States’ implementation of Community requirements on the treatment of dental amalgam waste, and will take appropriate steps thereafter to ensure correct application.

The promised review is presently underway, and this report is intended to contribute to that deliberation.

1 Elemental mercury exposure should not be confused with methylmercury exposure, largely resulting from the consumption of fish with elevated mercury concentrations.

2 In fact the European Commission has asked the Medical Devices Expert Group to consider the use of mercury in dental amalgam, and will seek an opinion from the Scientific Committee on Health and Environmental Risks, with a view to considering whether additional regulatory measures are appropriate.
In broad terms, the scope of this paper may be described as:

- Focusing on the contributions, mass balance and flows of dental mercury through the EU environment;
- Summarising legislation and policies dealing with these flows; and
- Making specific observations with regard to the management of dental wastes, and the use of mercury in dentistry.

1.2 Organisation of the paper

This paper first describes, in general terms, the many pathways that dental mercury follows into the environment. Based on an understanding of those pathways, it then develops an EU-27 “mass balance” for dental mercury, i.e., identifying the eventual environmental destination of all mercury introduced by dental practices during the course of a year. That analysis is followed by a discussion of dental mercury becoming bioavailable and potentially affecting the health of humans and animals, a discussion of the real cost of continued use of mercury in dental applications, and a review of relevant legislation and policies.

1.3 The mercury problem

Mercury and its compounds are highly toxic to humans, ecosystems and wildlife. High doses can be fatal to humans, but even relatively low doses can have serious adverse neurodevelopmental impacts. They have also recently been linked with possible harmful effects on the cardiovascular, immune and reproductive systems (European Commission 2005).

Mercury is persistent and can change in the environment into methylmercury, one of the most toxic forms. Methylmercury readily passes both the placental barrier and the blood-brain barrier in pregnant women, inhibiting potential mental development even before birth. Methylmercury collects and concentrates especially in the aquatic food chain, making populations with a high intake of fish and seafood particularly vulnerable (European Commission 2005).

People eating fish contaminated with methylmercury are at risk of potential damage to the brain, heart and other organ systems. It is generally agreed that young children and developing foetuses are at the greatest risk of methylmercury exposure. US EPA scientists have estimated that around 300,000 children – or one newborn in ten – are born at risk of neurological harm each year in the U.S. as a result of maternal exposure to methylmercury (Mahaffey 2004).

Most people in central and northern Europe show bio-indicators of exposure below internationally accepted safe levels for methylmercury. However, there is evidence of continuing exposures at or above these levels among some of the European population, and especially in coastal areas of Mediterranean countries and the Arctic (European Commission 2005).

Although mercury is released by natural sources like volcanoes, additional releases from anthropogenic sources, like coal burning and use in products, have led to significant increases in environmental exposure and deposition. Past and ongoing releases have created a “global pool” of mercury circulating intercontinentally through the biosphere, part of which is continuously mobilised, deposited and re-mobilised. Further mercury releases add to this global pool circulating between air, water, sediments, soil and biota (European Commission 2005).
Mercury amalgam waste increases the load of mercury to both the local and global environment, as well as exposure to methylmercury through fish in the diet (US EPA 1997).

For these reasons the EU and many other countries working through the United Nations Environment Programme (UNEP) have repeatedly underlined the importance of reducing the quantity of mercury circulating in the biosphere. This “global pool” of mercury may be considered to be roughly proportional to the uptake of methylmercury by fish, which is the greatest overall source of exposure to humans (European Commission 2005).

A broad range of efforts are therefore underway in the EU and around the world, in line with UNEP mandates, to reduce both local pollution and the global pool of mercury in the biosphere. To the extent EU dental mercury contributes to this in a significant way, then appropriate measures should be taken to reduce the EU contribution.

2 Dental mercury pathways to the environment

2.1 Pathways of dental mercury through the economy and society

The main pathways of dental mercury through the economy and society include:

1. mercury supply sources;
2. mercury brokers and traders;
3. suppliers of amalgam products to the dental trade;
4. application of mercury in dental practices;
5. dental mercury in waste streams;
6. recycling or storage of mercury; and
7. the eventual disposition of dead bodies with mercury fillings, whether by burial or by cremation.

This analysis has concentrated mostly on the series of activities numbered 4 through 7 above, i.e., the activities that take place in the dental clinic – amalgam waste generated prior to the placement of a filling; the excess material carved from new amalgam fillings; the removal of old amalgam fillings; the removal of teeth containing amalgam; other mercury going to solid waste or wastewater; mercury emissions directly to the air; the traps, filters and other devices in dental clinics to remove mercury from the wastewater – and the “downstream” flows of mercury from there.

Most dental mercury waste results from the removal of previous fillings from patients’ teeth. Together with waste from new fillings, removed teeth, etc., these dental wastes typically follow several main paths. They may be captured for subsequent recycling or disposal, they may be flushed down drains that lead to the general municipal wastewater system, they may be placed in special containers as medical waste, or they may be put in the waste bin as municipal waste.

Figure 1 is a simplified illustration of the general flow of mercury through the dental clinic and downstream. Among other details, it does not show, for example, that mercury may be released to the air both within the clinic and from the clinic wastewater system, nor does it make clear that mercury may be released by certain dental techniques (e.g. cleaning or
polishing mercury amalgams) even when fillings are not placed or removed. These releases are, however, taken into account in the analysis carried out in later sections of this report.

Figure 1 - General flow of mercury through the dental clinic

Next to each dental chair most dental facilities have a basic chairside filter (or trap) in the wastewater system to capture the larger amalgam particles, and some have secondary vacuum filters just upstream of the vacuum pump. In addition, separator technologies are now available that can potentially remove over 90% of the mercury from wastewater. These are discussed further below.

2.1.1 Beyond the scope of this paper

As mentioned above, this discussion will not focus on mercury releases from primary sources supplying mercury to the dental industry, such as mercury mines, by-product mercury sources, residual mercury from decommissioned chlor-alkali facilities, or recycling,
although environmental releases from some of these operations can be significant (UNEP 2005).

Nor will this paper discuss the next level of the supply chain – the brokers and other mercury traders – whose operations are not typically associated with significant mercury releases in the EU except in the case of accidents.

Nor will this paper treat in any detail the production facilities – potential sources of mercury emissions and wastes – that transform elemental mercury and other metals into the commercial pre-packaged dental amalgam capsules now used by most dental practitioners in the EU.

2.2 Mercury waste from dental applications

Mercury can enter the environment from a number of paths. For example, if a mercury-containing item is thrown into the waste bin, the mercury may be released into the atmosphere from landfill vapours or leachate, or the mercury may vaporize if the trash is incinerated. If mercury is flushed through a wastewater system, the mercury will likely adhere to the wastewater sludge, where it has the potential to volatilize and be deposited elsewhere. Mercury can enter the atmosphere through these various means because it evaporates easily. It then travels through the atmosphere in a vaporized state (Wisconsin Mercury Sourcebook 1999).

Once mercury is deposited into lakes and streams, or in the open ocean, bacteria convert some of the mercury into an organic form called methylmercury. This is the form of mercury that humans and other mammals ingest primarily through eating fish, although some communities suffer exposure through the consumption of marine mammals as well. Methylmercury is particularly dangerous because it bioaccumulates in the food chain. Bioaccumulation occurs when the methylmercury in fish tissue concentrates as larger fish eat smaller fish (Wisconsin Mercury Sourcebook 1999).

2.2.1 Wastewater system

It is commonly accepted that most municipal wastewater systems have relatively high levels of mercury, and it has been determined that much of that mercury originates from dental practices (AMSA 2002a). The quantity of mercury going to wastewater systems from dental clinics is difficult to quantify (see Section 3), but it is clear that even the better municipal wastewater treatment systems are not intended to treat or remove mercury from the wastewater stream. Therefore most of the mercury entering the wastewater stream will concentrate in the sludge or “biosolids,” and the rest will be discharged to downstream surface waters along with the treated effluent.

It should be noted that various conditions during the wastewater treatment process may be favourable to the methylation of mercury. Furthermore, since most water treatment facilities dispose of sludge waste by spreading it on agricultural or other land, or by incineration, there is the further opportunity for mercury to follow these pathways especially to surface water runoff (and methylation) and to the atmosphere (and later deposition, partial methylation and uptake in the food chain).

2.2.1.1 Dental clinic and piping system

Over many years the piping systems in dental clinics have accumulated mercury that settles to low parts of the system, sumps, etc., or may attach itself to the inside of a metallic piping
system. The slow dissolution and re-release of this mercury may be sufficient, even after dental clinic emissions have been greatly reduced, to exceed wastewater discharge standards, and may serve as a long-term source of mercury to a wastewater treatment facility. For example, large amounts of mercury were recovered (average 1.2 kg per clinic) during the remediation of 37 abandoned dental clinics in Stockholm in 1993–2003 (Engman, 2004). Similar accumulations were observed by Hylander et al. during more recent work in several Swedish dental clinics (Hylander et al. 2006a).

Therefore, any serious maintenance work on a dental clinic wastewater system should ensure that all pipes and plumbing fixtures are cleaned and/or replaced since they have long accumulated mercury wastes and constitute an ongoing source of mercury releases.

2.2.1.2 Septic tanks

In areas lacking a public wastewater system, dental practices may still be connected to septic systems. As in parts of wastewater treatment systems, certain conditions may exist in a septic tank that promote the methylation of mercury, which may pollute local soils and groundwater. Likewise, sludges may be periodically removed and dispersed over agricultural and other soils, or contribute to the mercury loading at wastewater treatment facilities.

2.2.2 Solid waste stream

Mercury-containing solids and sludges removed from traps and filters are increasingly being recycled or disposed of as hazardous wastes.

2.2.2.1 Municipal landfill and incineration

Despite regulations regarding the characterisation and disposal of mercury bearing wastes, many solid dental wastes still follow the low-cost route of disposal as municipal solid waste and are subsequently disposed of in landfills or by municipal incineration. Depending on the characteristics of the landfill, dental amalgam may decompose over time and the mercury may enter the leachate (which may itself be disposed of in a manner that permits the mercury to be released), groundwater, soils, or volatilise into the atmosphere. Studies have documented methylmercury in gases emitted from landfills (Lindberg et al. 2001). Municipal incinerator operators will not accept mercury waste if they are able to identify it in advance, but it often enters the solid waste stream unmarked.

2.2.2.2 Hazardous waste landfill and incineration

The regulations for hazardous waste treatment in the EU are stricter and more closely monitored than those for municipal waste. Therefore, both hazardous waste landfills and incinerators are better equipped to deal with mercury wastes, and to minimise releases. On the other hand, because this disposal path is typically more expensive than recycling, dental professionals may be reticent to send dental wastes to hazardous waste disposal.

2.2.3 Air emissions

Mercury emissions to the air from dental clinics may occur during handling and placing of mercury amalgams, or they may occur as releases from the wastewater system.
2.2.3.1 Air emissions during dental work

Dental personnel may be exposed to the following sources of mercury vapours: “accidental mercury spills; malfunctioning amalgamators, leaky amalgam capsules or malfunctioning bulk mercury dispensers…; trituration, placement and condensation of amalgam; polishing or removal of amalgam; vaporization of mercury from contaminated instruments; and open storage of amalgam scrap or used capsules” (JADA 2003).

2.2.3.2 Air emissions from the dental clinic wastewater system

As mentioned, dental clinical procedures generate mercury wastes, slurry and fine particulate matter from mercury amalgam filling materials. Many of these wastes are discharged into the municipal wastewater system via the clinic vacuum pump or a similar system. This system may also discharge large volumes of air, including mercury vapour, either into the atmosphere outside the dental clinic or into the sewer system, depending on the type of equipment used (Rubin and Yu 1996).

2.2.4 Medical waste treatment

A survey in the USA in 2000 discovered that 25-30% of dentists disposed of much of their dental amalgam waste as medical waste due to the potential presence of pathogens (KCDNR 2000). Typically medical waste is disposed of by incineration, or sometimes by a sterilisation process known as “autoclaving” (common in Ireland, for example). Medical waste incinerators are now supposed to operate according to EU regulations limiting emissions of mercury, although autoclaving remains less regulated and could result in mercury vapour releases, discharge of effluents to the wastewater system and/or eventual landfilling of autoclaved waste (HCWH 2002).

2.2.5 Recycling

Various Member States of the EU have reported that recycling of dental amalgam wastes is increasing as dental professionals responsibly deal with mercury wastes. This is a logical way to deal with large amounts of amalgam waste with a high mercury content, and the typical high-temperature retorting process employed by recyclers is also able to address any concerns about pathogens in the amalgam wastes.

It should be kept in mind that the recycling process also generates some air and water emissions of mercury, but these should be quite low in accordance with EU and member state regulations. Some stakeholders are further concerned about the fate of the mercury after recycling, noting that it may end up being sold for use by artisanal gold miners, the manufacture of skin-whitening creams or other applications that are associated with sizeable and/or diffuse mercury releases. However, a mercury export ban regulation is now under consideration in the EU Parliament, and will likely soon prohibit such mercury exports.

2.2.6 Mercury storage and final disposal

Until fairly recently, most dentists had stocks of mercury in their clinics which they used, in the past, to make dental amalgams by hand. Since relatively few Member States in the EU have made efforts to recover these stocks of mercury, it is reasonable to assume that there remain substantial quantities of mercury in storage in dental clinics. These stocks of mercury are at risk of accidents, improper disposal or other releases due to neglect.
Several Member States have developed facilities for final disposal of hazardous wastes in deep bedrock or salt formations, and some dental amalgam wastes are sent to these facilities for final disposal. For purposes of this study, it is assumed that there are no further mercury releases of any significance from such “final disposal” facilities.

2.2.7 Burial

Mercury fillings continue to pose a pollution problem after death, and most often end up in a cemetery, from where the mercury will eventually enter the soil and/or groundwater. Furthermore, as burial space is increasingly limited in parts of some Member States of the EU, previous burials are sometimes dug up in order to make room for new burials. Since previous burials likely have dental amalgams as well, and these amalgams may already be in a certain state of deterioration, it would be useful to understand how these remains are being disposed of.

2.2.8 Cremation

As described in detail in Section 3.2.3.2 below, cremation is a common practice in the EU and it is increasingly being used across the continent. Cremation is typically carried out at a temperature that vaporises virtually all of the mercury in any dental amalgams, although it has proven quite difficult to balance the amount of mercury believed to be in dental amalgams with measurements of mercury emissions in the crematorium flue gases. Depending on the crematorium design, it appears that some mercury may adhere to different parts of the flue gas system and not be immediately emitted from the stack. Furthermore, crematoria are usually located within cities and close to residential areas, and stacks tend to be relatively low (UNEP 2003).

2.3 EU waste-related regulations

There are a range of EU regulations to limit the mercury content of wastewater, to define hazardous waste, to limit mercury emissions to the air from industrial facilities and incinerators, to limit the mercury content of sludges disposed to agricultural and other soils, to require routine reporting of certain waste categories, etc. (details may be consulted in European Commission 2005). However, these have not been consistently applied by Member States, especially with regard to the specific case of mercury in dental amalgams.

For example, mercury-containing dental amalgam waste is considered to be hazardous waste within the EU and must be disposed of in accordance with applicable laws (EEC 1991). However, transposition of EU legislation to the member state level, not to mention enforcement, has not been consistent. In 2004 the Commission notified the UK that amalgam filters, as a minimum, are necessary to comply with Article 4 of the Waste Framework Directive. This followed an investigation that “revealed weaknesses in the UK's implementation of the Waste Framework and Hazardous Waste Directives in relation to this type of waste,” and in which the Commission discovered that dental amalgam was not being treated as a hazardous waste in the UK, but rather released directly into the environment by most dental clinics (European Commission 2004a). The Commission's Mercury Strategy consultation document indicated that many other Member States were similarly lax in addressing the collection and disposal of amalgam waste at dental practices (Council 1999).

Further discussion of relevant regulations may be found in Appendix I.
3 EU-27 dental mercury mass balance

3.1 Dental use of mercury

3.1.1 The “human inventory” of dental mercury

The extent of dental use of mercury in the EU is highly variable from one country to another, and there are a range of estimates of the amount of mercury carried in people’s mouths.

Sweden has estimated that there are about 40 tonnes of mercury in the teeth of its citizens (Keml 2004), which is equivalent to about 4.5 g average for each of Sweden’s 9 million citizens. However, since only 74% of Swedes have fillings, the actual average is closer to 6 g mercury per citizen with fillings. As a national policy, the use of mercury fillings in Sweden is becoming increasingly rare; the country estimated its annual use of mercury for dental applications at only about 100 kg in 2003 (Sweden 2005).

France has estimated its human dental inventory at about 100 tonnes of mercury, which is an average of less than 2 g per person in the mouths of France’s population of around 60 million. However, it has also been estimated that France consumes some 35 tonnes of mercury/year for dental purposes (Piren-Seine 2004, as cited by France 2005), suggesting either a recent emphasis on improved dental care, or an especially high replacement rate for amalgam fillings already in place, or perhaps an underestimate of the human dental inventory.

An estimate for the US in 2004 has been given as about 1000 tonnes of mercury – equivalent to approximately 3.5 g of mercury per person.

It has been estimated for the EU-15 and EFTA countries that an inventory of 1300 to 2200 tonnes of mercury is present in the dental fillings of the population (Hylander 2002; EU 2004). This estimate may be somewhat high. In estimating the dental mercury load of the average person at the time of death – generally assuming that virtually all mercury in amalgams is released during cremation – various countries have developed the figures in Table 1 below.

<table>
<thead>
<tr>
<th>Country/State</th>
<th>Hg release (g) per cremation</th>
<th>Sources, comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>1.0</td>
<td>OSPAR (2006) cites a calculation carried out by TNO.</td>
</tr>
<tr>
<td>Denmark</td>
<td>4.0</td>
<td>OSPAR (2006).</td>
</tr>
<tr>
<td>Germany</td>
<td>0.5-3.0</td>
<td>OSPAR (2006).</td>
</tr>
<tr>
<td>Norway</td>
<td>5.0</td>
<td>OSPAR (2006).</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3.0</td>
<td>Knellwolf (2003), Reindl (2007).</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.9</td>
<td>OSPAR (2006). This emission estimate is based on the average measured mercury emissions of 18 cremations, with no mass balance performed to determine the fate of the rest of the mercury in the teeth of these corpses.</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1.92</td>
<td>2004 Defra consultation</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3.0</td>
<td>2002 UK National Atmospheric Emission Inventory</td>
</tr>
<tr>
<td>USA</td>
<td>1.0-5.6</td>
<td>US EPA (2005).</td>
</tr>
</tbody>
</table>
While the range of estimates is large, they converge at approximately 3 g mercury per person cremated. Since most deaths are among older persons, one might assume that virtually all of them have mercury fillings, whereas many young persons do not. On the other hand, because they have fewer of their natural teeth, on average, older persons tend to have less amalgam in their mouths than the average adult (Defra 2004). Therefore, in very general terms, for the entire EU-27 population of some 500 million persons, one might conservatively assume that three-quarters of the population have an average of 3 g of mercury in their mouths, or that the entire population has an average of 2.0-2.5 g of mercury in their mouths – both sets of assumptions leading to an estimate of over 1100 tonnes “human inventory” of dental mercury. With slightly different assumptions this estimate could be as high as 1300-1500 tonnes of mercury, but the reality is surely not less than 1100 tonnes.

3.1.2 Mercury consumption by the dental profession

Annual consumption of mercury in the EU-25 was recently estimated as shown in Figure 2, suggesting a range of some 80-100 tonnes/year for dental uses. It may be assumed that consumption for the EU-27 is around 10% greater – roughly in line with the population differential – bringing the total to 90-110 tonnes/year. But this estimate may also be a bit low, as demonstrated by an alternative approach for approximating the EU consumption of mercury for dental uses.

In a US Geological Survey report published in 2000, it was noted that the average life of a mercury amalgam filling is reported to be from 5 to 8 years, while in a 1995 article in a Swiss dental medicine journal (Matter-Grütter), the average life was stated to be 10 years. Ten years is also the assumption used in the UK Department for Environment, Food and Rural Affairs’ 2nd consultation (Defra 2004). Other estimates are occasionally as high as 10-20 years (Reindl 2007). If the human inventory of dental mercury in the EU is in fact at least
1100 tonnes, and if one assumes the average life of an amalgam filling to be 10-12 years, this is generally consistent with the placement of about 100 tonnes of dental mercury in the mouths of EU citizens each year. However, it is normal that there is some amalgam carved away or otherwise lost during a typical clinical procedure – averaging some 20-25% of the total amalgam. Therefore the annual consumption of mercury in the EU-27 by the dental profession is likely in the range of 125 tonnes.

As a very rough check, this second estimate is consistent with information from the five countries that estimated dental mercury consumption in communications with the European Commission (France 2005; Germany 2005; Netherlands 2005; Sweden 2005; and UK 2005) – totalling about 53 tonnes of mercury, and representing about 47% of the EU population. It may also be noted that most of these countries have initiated efforts to reduce the use of mercury in dental applications. As seen in Figure 2 above, after the chlor-alkali industry, the consumption of mercury for dental amalgam is by far the most significant use of mercury in the EU, and for this reason, along with the difficulty of controlling its various paths into the environment, it has attracted considerable attention from policy-makers and others.

3.1.2.1 Trends

In many higher income countries, dental use of mercury is now declining (Finland comments, 2006; ADA comments, 2006). The main alternatives are composites (most common), glass ionomers and compomers (modified composites). However, the speed of decline varies widely among countries, so that dental mercury use is still significant in most countries of the EU, while in Sweden and Denmark it has nearly ceased. In lower income countries, changing diets and better access to dental care may actually increase mercury use temporarily, especially where the cost of treatment is most critical. With reference to the EU it may be concluded:

> Advances in mercury-free dental care, and reductions in mercury use in many countries will be offset by improved dental care in others, including likely increased use of inexpensive and low-tech mercury amalgam fillings. While aesthetic considerations may encourage whiter fillings, and new materials will gradually come on the market, a conservative approach would assume that [under present policies] there will be little or no reduction in mercury use to 2020 (Maxson 2006a).

Among others, Sweden, Japan, Denmark, Norway and Finland have implemented measures to greatly reduce the use of dental amalgams containing mercury.

### 3.2 Mercury waste from dental applications

Dental offices are a well-documented and significant source of mercury discharges to water.

#### 3.2.1 New amalgam fillings and old amalgam removal

If the consumption of “new” mercury in the EU-27 by the dental profession is assumed to be 125 tonnes, this implies that about 100 tonnes ends up in teeth, and some 25 tonnes is discarded as waste. It has been estimated that about 70% of amalgam fillings are replacements of previous amalgam (MPP et al. 2006, citing the American Dental Association), and 30% are new fillings. Therefore, 70 tonnes of the 100 tonnes are assumed to replace previous fillings, implying that the previous fillings also contained about 70 tonnes
of mercury,\textsuperscript{3} which is removed and goes into the waste stream. In total the mercury content of this liquid/solid waste stream then comprises some 25 t discards + 68 t removed amalgam = 93 tonnes of mercury.

Overall, the 32-tonne difference between the 125 tonnes of mercury consumed by the dental industry and the 93 tonnes just calculated that enter the clinics’ liquid/solid waste stream may be explained by mercury in teeth that are lost or extracted, mercury in teeth of deceased persons, and direct mercury emissions to the air, as explained in following sections.

Through the use of amalgam removal systems such as chairside traps/meshes, vacuum filters and separators\textsuperscript{4} in the wastewater stream from dental clinics, mercury removal efficiencies of 95-99\% can theoretically be achieved, although in practice any or all of these systems may be missing or improperly maintained. Therefore, the actual level of amalgam removal from the wastewater system is typically far lower.

Figure 3 below shows the two main types of wastewater flow systems installed in dental clinics. Without any added separator, the “dry” vacuum pump system removes an estimated 30-40\% of the mercury in the waste stream, whereas the “wet” vacuum pump system, incorporating an additional vacuum filter, may remove up to 50\%. If a “separator” is installed, efficiencies of 80-85\% total mercury removal may realistically be achieved if the system is properly maintained (Hylander \textit{et al.} 2006a, 2006b and personal communication).

Figure 3 - Typical dental clinic waste flow systems (without amalgam separator)

\textsuperscript{3} In fact the previous fillings may have contained a few percent less, assuming some of the mercury has vaporised as described in Section 3.4.4, and the previous fillings were slightly smaller.

\textsuperscript{4} A CEN standard for a Dentistry Amalgam Separator has been developed, see http://www.cenorm.be/CENORM/ BusinessDomains/TechnicalCommitteesWorkshops/CENTechnicalCommittees/WP.asp?param=6039\&title=CEN/TC\% 2055. The ISO equivalent standard is ISO 11143, which is currently under revision.
It should also be noted that both of these systems must be vented to the air. Research carried out in the US (Rubin and Yu 1996) measured mercury releases from the wastewater system per dentist at about 60 mg/day. Extrapolation of that observation to the EU-27 suggests air releases from the dental wastewater system may exceed 3 tonnes per year.

The enforcement of the requirement to install amalgam separators and manage mercury-laden solid wastes from dental offices as hazardous waste is a critical first step. However, even when properly used and maintained, separators are not 100% effective and in any case, mercury from amalgams enters the environment through other pathways. The Swedish, Danish and Norwegian governments have therefore taken the position that the placement of mercury fillings should be phased out.

In the meantime, in Sweden, Norway, and Denmark amalgam separators are now used in the majority of dental clinics. Amalgam separators are also in wide use in Austria, Finland, the Netherlands and Switzerland, and increasingly in Belgium, Germany, France and the Czech Republic (KemI 2004; Norway 2003; GMA 2002; Belgium 2005; Czech Republic 2005; France 2005; Germany 2005; Sweden 2005).

Although amalgam separators have been required since 1979 in Sweden (GMA 2002) and led to significant reductions in mercury emissions to wastewater, there are deficiencies in the effectiveness of amalgam separators. A 1998 study found that one in four separators in Stockholm did not operate correctly, leading to excessive discharges, and more recent investigations have discovered that problems persist (Hylander et al. 2006a and 2006b).

Perhaps due to European Commission interest as demonstrated by the Community Mercury Strategy, it is evident that increasing attention is being paid within EU countries to the proper collection and disposal of dental amalgam. However, despite the apparently advanced level of legislation, regulations and guidance implementing the Hazardous Waste Directive, many questions may be raised about the level of compliance on the ground: the number of clinics that have actually installed separators; confusion among definitions of traps, filters,
separators, etc., in assessing compliance; inspection of dental clinics to ascertain the level of compliance; procedures or penalties to deal with non-compliance; the theoretical efficiency of amalgam separation equipment vs. actual practice; the difference between installing separation equipment and operating it properly; the need for routine and competent maintenance in order for separation equipment to achieve a high level of efficiency, etc., not to mention the difference between rated efficiency and actual efficiency; and last but not least, the actual disposition of mercury amalgams once they have been collected/separated by filtering and separation devices.

For the purpose of establishing a rough mass balance for dental mercury, it is estimated that 40-50% of the mercury passing through chairside traps/filters is captured, although Christensen et al. (2004) have suggested the percentage is lower. It is further assumed that separators capture perhaps 70-80% of the mercury passing through. Based on four US studies cited by Bender (2002) and rough guidelines provided by EU-27 data, it is estimated that some 40-50% of the mercury not captured by separators or disposed of directly to the municipal solid waste system goes into the municipal wastewater system, while the rest is assumed to be captured by chairside traps and filters. Therefore, of the total 93 tonnes of mercury in waste dental amalgams in 2006, about 30 tonnes is thought to have been captured by chairside traps and filters and another 23 tonnes by separators, about 14 tonnes were disposed of directly to the municipal solid waste system, nearly 4 tonnes were emitted directly to the atmosphere, and the remaining 23 tonnes went into the wastewater system without any filtration in the dental clinic.

Based on the disposal methods for collected dental amalgam as reported by various Member States that responded to a DG Environment request for information (Austria 2005; Belgium 2005; Czech Republic 2005; Finland 2005; France 2005; Sweden 2005), it is estimated that of the 53 tonnes of mercury retained in traps, filters and separators, about 40% were recycled, 30% were disposed of as hazardous waste, 15% were mixed with medical waste, 10% were disposed of as municipal solid waste and 5% were returned to the wastewater system.

3.2.2 Lost and extracted teeth

In addition to the above waste, there is also significant mercury contained in teeth that are lost or extracted. While the statistics vary, based on the rather comprehensive studies of Defra (2004) and Christensen et al. (2004), the quantity of mercury in lost or extracted teeth is estimated here as a fraction (about one-sixth) of the total quantity of mercury in old amalgams being replaced, coming to about 11 tonnes of mercury. Due to the nature of this waste – mostly still attached to teeth – it is estimated that some 30% were disposed of as medical waste, 20% as hazardous waste, 30% as municipal solid waste, and 20% to recycling.

3.2.3 Deceased persons

As noted previously, there is increasing concern about the ultimate destination of the mercury in people’s teeth after death. Therefore, it is useful to look more closely at burial and cremation practices.

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5 Also, some Member States indicated 40-45 tonnes of mercury in the form of “EWC 18 01 10 - amalgam waste” collected/recycled/disposed around 2003-2004 (Belgium 2005, France 2005, Germany 2005, UK 2005, Finland 2005, Czech Republic 2005, Sweden 2005 and Netherlands 2005), although it is not possible to confirm that these quantities were all generated during one year.
The mercury content per corpse is said by several sources to be gradually increasing due to better health care and the fact that older people are retaining more of their original teeth – albeit with tooth fillings containing mercury. Due to the longevity of mercury fillings, it is generally assumed that most fillings are placed during the last 10-15 years of dental treatment before death. Therefore any shifts in dental practices away from mercury fillings will be reflected rather rapidly (over 10-15 years) in the amounts of mercury present at the time of cremation. Nevertheless, with regard to total mercury in the teeth, over the medium term gradually reduced use of amalgam may be counterbalanced by the gradually increasing number of original teeth at the time of death.

3.2.3.1 Burials

Recent trends in burials compared to cremations in the EU-27 are summarised in Figure 4. Referring back to the estimate of 3 g mercury per deceased person developed in Section 3.1.1, using the number of 4.6 million deaths in the EU-27 annually (CSGB 2004), and assuming that about two-thirds of these bodies are buried results in about 9 tonnes of mercury following this pathway into the environment every year.

Figure 4 - Recent trends in EU-27 cremations vs. burials

The medium- to long-term transfer of mercury from the teeth of buried corpses to the environment has not been widely researched, but appears to be a legitimate cause for concern (GMA 2002; Defra 2004). While the rate of release of this mercury is uncertain, it makes sense to assume that it will gradually decompose, with perhaps 80% remaining in the soil and 20% eventually reaching groundwater.

3.2.3.2 Cremations

The Cremation Society of Great Britain provides rather comprehensive statistics on cremations in the EU-27 (CSGB 2004), amounting to nearly one-third of all EU deaths, and based on previous assumptions, releasing about 4.5 tonnes of mercury annually.
A report from the United Kingdom Department for Environment, Food and Rural Affairs (Defra 2003) came to the following conclusions, among others, with regard to mercury emissions from crematoria:

- It estimated that the amount of mercury from cremations will increase in the UK by two-thirds between 2000 and 2020, accounting for between 11% and 35% of all mercury emissions to the air in 2020. The upper figure is consistent with UK emissions as reported to UN/ECE and EU. Other major sources of atmospheric mercury in the UK include zinc ore smelting, coal and coke burnt in power stations, coal burnt in other countries, the chlor-alkali industry and clinical waste incineration.

- After 2020 the emissions of mercury from cremations are expected to stabilize or continue rising slightly to 2035, followed by a decrease back to 2000 emission levels around 2055, based on an expected decline in the use of mercury in current and future dental restorations.

- It concluded that dealing with the mass of mercury emitted from crematoria is more important than addressing the different species of mercury emitted.

- The human health concerns are rather more closely related to the long distance transport of mercury than to local deposition; mercury levels around crematoria are generally below those that are believed to give rise to health concerns.

These conclusions reinforced those of Tauw Milieu (Coenen 1997, as cited by Defra 2003) that predicted for the Netherlands a doubling of mercury emissions from crematoria between 1995 and 2020, and a 68% increase for the period 2000 to 2020. However, this assumes an increase in the average number of fillings per person (OSPAR 2003), and to the extent that mercury amalgam is gradually substituted by mercury-free alternatives, the potential mercury emissions associated with an increased number of fillings may be minimised.\(^6\)

Figure 5 demonstrates the relatively rapid increase in cremations throughout the EU-27 during the period 1996 to 2004.

In France the rate of cremations increased from 2% of deceased persons in the 1970s to 16% in 2000, and the number of cremation ovens increased from 90 to 110 in the two years preceding the 2003 OSPAR report.

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\(^6\) Abatement measures for new crematoria have been obligatory since 1999 in the Netherlands, and must be implemented by the end of 2006 or 2012 for large and small existing crematoria respectively.
Crematoria are one of the largest sources of mercury emissions to air in Sweden. The Swedish EPA calculated emissions from crematoria at 123 kg of mercury in 2001. In Sweden 70% of the dead are cremated, and just over half of cremations take place with flue-gas scrubbing. Even with the removal of mercury from the flue gases, a mercury-containing waste is produced that must be dealt with as a hazardous waste for final disposal. As the use of mercury amalgam in Sweden diminishes, mercury emissions from crematoria will also decrease over the longer term (Sweden to CT 2005).

OSPAR Recommendation 2003/4 on Controlling the Dispersal of Mercury from Crematoria is in the process of being implemented in all countries that are party to OSPAR (i.e., EU countries Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK, as well as non-EU countries Iceland, Norway and Switzerland). According to the available data, EU Member States where cremation is carried out but which are not party to the OSPAR Convention include Austria, the Czech Republic, Estonia, Hungary, Italy, Latvia, Poland, the Slovak Republic and Slovenia (European Commission 2005).

In conclusion, emissions from crematoria are expected to rise. There are two simultaneous trends contributing to this: a rise in the average number of fillings per person cremated (due to increasing numbers of original teeth), and a rise in the number of cremations. If the OSPAR Recommendation is responsibly implemented, the anticipated increase in the

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7 In October 2003 the Swedish Parliament passed a law that by 2015 waste containing 1% mercury or more by weight must be disposed of permanently in deep bedrock. The mercury content limit will be further reduced to 0.1% mercury by weight if that is determined to be reasonable within the meaning of the Swedish Environmental Code.
number of cremations and mercury fillings may not translate into significantly larger atmospheric emissions (European Commission 2005), at least for the OSPAR countries. However, a recent OSPAR report on the implementation of mercury controls on crematoria among countries that are party to the OSPAR Convention indicated that at the end of 2005 the installation of devices on crematoria for the specific control of mercury emissions was not very far advanced (OSPAR 2006).

While it is accepted that most mercury releases from crematoria go to the atmosphere (NJMTF 2002), some mercury is released as well during landfill disposal of residues, and possibly a small amount to the wastewater system, not to mention hazardous waste disposal of mercury in flue gas scrubbing and filter wastes of some crematoria. Reindl (2007) has cited an informal estimate of 75% mercury releases to the air and 25% releases to the soil, based on limited observations that all of the mercury in a corpse sometimes does not appear immediately in the stack gases. For the EU-27 it is estimated here that 80% of mercury during cremations is released to the air and 20% is released to the soil.

There is also national legislation in some countries where cremation is common, but which are not parties to the OSPAR Convention (see also Appendix I-A.3). One of the non-OSPAR Member States with its own emission standards is the Czech Republic (Czech Env Min 2002), which has decreed that the sum of cadmium, mercury and thallium emitted from cremation cannot exceed 0.2 mg/m$^3$. Similar emission limits have been established in some German States (Länder) and in Norway.$^8$

Figure 6 provides an indication of EU cremation trends and US projections to 2025.

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$^8$ 0.2mg/Nm$^3$ in Sachsen and 0.5 mg/Nm$^3$ in Brandenburg and in Norway.
3.3 Summary disposal pathways for dental mercury

Based on the previous analysis and assumptions, it is possible to present a rough picture of the main disposal routes for dental mercury, suggesting eventual pathways into the environment. The resulting diagram is presented in Figure 7 below.

![Figure 7 – Main disposal routes for dental mercury in the European Union – 2006 (metric tonnes)](image)

It may be observed that despite the quantities of mercury collected in traps, filters and separators, about 50% of the mercury in dental waste still ends up in municipal solid waste or wastewater, from where eventual releases to the environment may be high, as discussed below.

3.4 Final destination of dental wastes

3.4.1 Common waste disposal pathways

This section provides some further insight into the presence of dental mercury in the wastewater system and in municipal solid waste. Then it returns to the various disposal options for dental mercury and demonstrates the repartition of the mercury in dental amalgams among the main environmental media.
3.4.2 Dental mercury in the municipal wastewater system

Research has shown that the (74% of the) population in Sweden with amalgam fillings continuously release about 100 kg Hg/year to the wastewater system simply by chewing, swallowing and excreting (Skare and Engqvist, 1994; KemI, 2004). If the total EU population has fewer fillings, on average, than the Swedes and releases even less mercury via chewing, etc., it could still amount to 2-3 t Hg/year to wastewater from this source. Miniscule but constant mercury releases from mercury amalgams are ingested and then excreted by the body, entering the wastewater system and the environment, partially methylating and accumulating up the food chain to fish, and potentially returning to humans in the form of methylmercury in the diet. Among other environmental concerns, this is one reason that has been cited by the Swedish Chemicals Inspectorate for a phase-out of mercury amalgam (KemI 2004).

Sewage sludges are largely a product of the municipal wastewater system, but may also result from operations dealing with treatment of landfill leachates, etc. In Sweden the use of mercury in dental amalgam has been identified as the single largest source of mercury in sewage sludge (Ekblom 2005). Since mercury releases from dental practices have been greatly reduced in line with government policies, nearly half of the relatively low levels of mercury in Swedish sewage sludges is released from amalgam fillings while they are in the mouth, and the remaining mercury is from dental clinics, including mercury that has settled in wastewater piping systems (Ekblom 2005). According to studies carried out by the Stockholm Water Company, there remain deficiencies in the effectiveness of amalgam traps. In some cases they are installed incorrectly, blockages occur and often the maintenance they receive is inadequate.

In Slovakia, where amalgam separators are little used, the mercury concentration in sludge from urban wastewater treatment has been reported at 3.2 mg/kg dry matter. Slovakia has therefore decided to control the mercury discharge from dental practices and clinics into the municipal wastewater system in order to meet a target for sludge of 2 mg Hg/kg dry matter (European Commission, personal communication).

As mentioned previously, wastewater treatment plants are not designed to sequester or recycle captured mercury (or other heavy metals). If anything, wastewater treatment operators may invest in municipal programmes designed to keep these substances from reaching the wastewater plant. If mercury solids enter a treatment plant, they eventually wind up in the grit (the initial coarse screen/filter on incoming wastewater) and/or the sludge/biosolids. Treatment plant grit is typically landfilled, leading to possible problems with leaching and/or volatilization. Sludge is often incinerated, landfilled or applied to land as fertilizer or compost. In the latter case, wastewater utilities are interested in improving the quality of sludges in order to increase their market value (Savina 2003).

3.4.3 Dental mercury in municipal solid waste landfill and incineration

Whether in dental offices or water treatment plants, captured mercury is often not sequestered from the environment. A 2000 study in King County, Washington (USA), found that more than three-quarters of dental offices did not recycle or sequester mercury-bearing waste captured in chairside traps and vacuum pump filters. Rather, they put it in the waste bin, included it with medical waste, stored it onsite for eventual disposal or flushed it down the drain (Savina 2003).
Even in Denmark, a country where efforts to deal with the dental waste problem are quite advanced, and instructions were widely distributed to dental associations and clinics, a recent study estimated that 20% of dental clinics still lacked separators (Christensen et al. 2004).

3.4.3.1 Land disposal of sewage sludge

As suggested above, the presence of mercury in sewage sludge makes it more difficult to use as an agricultural fertilizer, which has long been one of the main disposal options. Levels of mercury in soil are not presently controlled or monitored under Community legislation, although some aspects affecting soil quality (e.g. sewage sludge) are regulated. The thematic strategy on the protection of soil is intended to provide a basis for further action (European Commission 2005).

In 1999 the average mercury content of sludge spread on EU agriculture soils was estimated at 1.5 mg/kg of dry matter, implying the introduction of 4.3 tonnes of mercury to EU agricultural land annually (European Commission 2004b). Sludge is regulated by Directive 86/278/EEC of June 1986, which dictates that Member States must prohibit the application of sewage sludge to soil where the concentration of one or more metals in the soil exceeds certain limit values. For mercury the sludge limit value is 1 to 1.5 mg/kg of dry matter for spreading on soils with a pH higher than 6 and lower than 7. Member States must also regulate the use of sludge such that the accumulation of heavy metals in soil does not exceed other limit values.

The high mercury content in sewage sludge has led wastewater treatment facilities to search for other users willing to buy it, as mercury removal from sludge is not cost effective, and combustion of sludge in waste incineration plants or special incineration plants for sewage sludge is expensive (IPPC 2005). In some cases it is sold to combustion plants to be burned together with coal, but this leads to higher mercury emissions in the flue gases, which may increase the need for additional pollution control measures.

3.4.3.2 Municipal waste incineration

EU legislation requires that municipal incinerators limit mercury emissions, but they remain highly significant (Pacyna et al. 2005). While highly uncertain, it may be estimated from the UNEP Mercury Toolkit (COWI 2005) that the EU municipal solid waste stream contains some 0.3-1.0 ppm mercury. Assuming the EU generates on the order of 500 kg municipal waste/capita/yr, this is equivalent to 75-250 tonnes of mercury in the EU municipal solid waste stream. It will be demonstrated below that mercury attributable to dental uses may comprise 15-20% of that waste stream.

3.4.4 Dental mercury emitted directly to the air

Dental mercury emitted directly to the air may take various forms:

- air emissions from the clinic’s wastewater system,
- “occupational” air emissions inside the clinic, and
- air emissions from the mouths of the general public.

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The first of these has already been estimated in Section 3.2.1 at more than 3 tonnes of mercury per year.

Occupational air concentrations of mercury inside dental clinics are estimated to average about 15-20 µg/m$^3$, derived from Echeverria et al. (1998). This implies up to one tonne of dental mercury emissions to the air for all of the EU-27.

With regard to mercury “emissions” from the mouths of persons with dental fillings, it is noted that, depending on the number of fillings and other factors, the average daily absorbed dose of mercury from mercury-containing fillings has been estimated between 3 and 17 µg/person (US EPA 1997). Some estimates give a much higher range (Scarmoutzos & Boyd 2004). Further, approximately 80 percent of inhaled mercury vapour is absorbed by the lungs (US EPA 1997), of which most is later excreted. If roughly the same amount of mercury is exhaled as inhaled, then the average mouth will exhale about 5 mg of mercury during the course of one year, and the EU-27 will exhale around two tonnes to the atmosphere. This estimate agrees rather well with the estimate of mercury ingested and excreted that was developed in Section 3.4.2.

Combining inhaled and exhaled mercury, one can observe that during 11 years (taken here as the average life of a mercury filling) the average mouth containing about 3 g of mercury will lose more than 100 mg of mercury, or just above 3% of the mercury content of the fillings. While useful to keep in mind, this observation is considerably at odds with the findings of one researcher who calculated as much as 50 percent of the mercury in dental fillings vaporised after 5 years, and up to 80 percent after 20 years (Pleva 1994 and 1992), which seems extremely high.

3.4.5 Dental mercury in medical waste

As mentioned in Section 2.2.4, a significant amount of medical waste in the EU is disposed of through incineration or sterilisation processes, such as autoclaving, that may permit considerable mercury from dental amalgams to re-enter the environment.

3.4.6 Dental mercury in hazardous waste, deep underground disposal, retirement

It is assumed here that the mercury in dental amalgam and removed teeth that goes to disposal as hazardous waste, except for very limited emissions during treatment or possible incineration, may generally be considered to be safely disposed of with no possibility of becoming bioavailable in the environment.

3.4.7 Recycling of dental mercury

The process of recycling mercury wastes typically releases some atmospheric emissions, a very limited amount of mercury in solid waste residues, and some mercury in filters, etc., from flue gas cleaning. It is estimated here that, on average, over 95% of the mercury content of recycled amalgam wastes is recovered as elemental mercury.

3.4.8 Dental mercury disposal/media matrix

The scope of this paper does not permit a detailed investigation of the various disposal pathways for dental amalgam to different environmental media (air, water, soil and groundwater, unless the mercury has been effectively removed from circulation or returned to commerce). The interlinkages are complex; the waste fractions that take a given pathway
depend on such factors as the split of municipal solid waste between incineration and landfill, the size of the amalgam particles in the waste stream, the rate of decomposition of the amalgam in contact with other materials and at different pH levels, the leachate treatment method, the types of flue gas control devices on an incinerator, the disposition of municipal wastewater treatment sludges and incinerator slags and residues to agricultural and/or other soils, the chemical composition of those soils, the runoff from those soils, etc. Moreover, there are little or no EU-wide data for quantities of dental mercury following most of these pathways. Nevertheless, the previous observations, together with indications drawn from references in Section 7 (especially Norway 2006; MVS Solutions 2004; Christensen et al. 2004; Environment Canada 2001), facilitate estimates of the EU disposal path/environmental media matrix for dental mercury. This matrix is presented in Table 2 below, suggesting the percentages of mercury in dental waste that are likely to end up in the EU air, soil, water and groundwater.

Table 2 – Estimated EU disposal/media matrix for mercury in dental amalgam

<table>
<thead>
<tr>
<th></th>
<th>Clinic wastewater to air</th>
<th>Municipal solid waste</th>
<th>Municipal wastewater system</th>
<th>Biomedical waste</th>
<th>Hazardous waste &amp; retirement</th>
<th>Recycling</th>
<th>Burial</th>
<th>Cremation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>100%</td>
<td>30%</td>
<td>10%</td>
<td>25%</td>
<td>2%</td>
<td>2%</td>
<td>0%</td>
<td>80%</td>
</tr>
<tr>
<td>Surfacewater</td>
<td>0%</td>
<td>10%</td>
<td>40%</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Groundwater</td>
<td>0%</td>
<td>10%</td>
<td>20%</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Soil</td>
<td>0%</td>
<td>50%</td>
<td>30%</td>
<td>15%</td>
<td>0%</td>
<td>2%</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Recycled, retired, not</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>50%</td>
<td>98%</td>
<td>96%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>bioavailable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It should be emphasised that the municipal solid waste and wastewater streams, together with burial and cremation, are not intended to sequester mercury from the environment. It has been estimated in the USA that dental mercury typically contributes some 50% of the mercury load to municipal wastewater treatment plants (ADA 2003; CCCSD 2006).

3.5 Dental mercury mass balance

Integrating all of the dental mercury flows described previously with the disposal/media matrix in Table 2 permits the elaboration of an approximate mass balance diagram of EU dental mercury flow pathways and quantities. This is presented in Figure 8 below.

In general terms, Figure 8 shows 109 tonnes (rounded) of mercury releases from ongoing dental practices, plus another 14 tonnes of mercury in the teeth of deceased persons – for a total of some 123 tonnes – entering the EU waste stream annually, of which:

- approximately 46 tonnes may be removed from circulation and not released to the environment (of which 22 tonnes appear to be recycled and returned to commerce); and
- approximately 77 tonnes may end up in various environmental media, chiefly the soil (30 tonnes) and atmosphere (23 tonnes), but also important amounts to surface waters (14 tonnes) and groundwater (10 tonnes). In these environmental media the mercury may be expected to continuously circulate in the biosphere, partially methylate, enter the food chain and affect wildlife and human health.
These findings are consistent with recent estimates for the USA, which consumes less than one-third the dental mercury consumed in the EU. These researchers calculated a wide range of 6 to 32 tonnes of mercury emissions per year only to surface waters and the atmosphere from dental mercury amalgams (Scarmoutzos and Boyd 2004).

Other assessments have come to similar conclusions. The Norwegian Pollution Control Authority (SFT) has emphasised that the “reasons for proposing a prohibition on the use of
mercury, including amalgam fillings, are based on the harmful effects of discharges of mercury into the environment “[original emphasis] (Norway 2006).

The magnitude of these dental mercury releases to EU environmental media may be roughly compared to the quantity of mercury emitted and “lost” by the large EU chlor-alkali industry every year from facilities using mercury technology. In that case, the large mercury losses are the key reason for the tremendous political pressure on the chlor-alkali industry to convert to a mercury-free process (Maxson 2006b).

4 Dental mercury becomes bioavailable in the environment

4.1 Mechanisms of bioavailability

There has been some debate in recent years concerning the extent to which the mercury in dental amalgam may be transformed into methylmercury – thereby becoming “bioavailable” and susceptible to eventual uptake in the food chain. The main environmental and health problems connected with mercury releases are chiefly due to the bacteriological transformation of inorganic mercury to the highly toxic compound methylmercury, as described in the box below. As amalgam releases increase the load of mercury to both the local and global environment, they also increase exposures to methylmercury through the fish that people eat (US EPA, 1997).

---

Environmental conversion of dental amalgam to methylmercury

Dental amalgam (or silver filling) is a metallic alloy comprised primarily of mercury (42-58%) and silver (20-40%) with minor components of tin (4-17%) and copper (1-16%). Depending upon the particular brand of dental amalgam, it may also contain small concentrations (<2%) of zinc, indium, palladium and platinum.

The formation of methylmercury from dental amalgam requires two steps:

Step 1: Conversion of metallic mercury (the form of mercury in dental amalgam) to inorganic mercury.

Step 2: Conversion of inorganic mercury to methylmercury. Once mercury is in the methyl form, it bioaccumulates up the food chain.

Step 1

The conversion of metallic mercury to inorganic mercury is not a spontaneous chemical reaction and it requires oxidizing agents, in particularly oxidizing agents of sufficient strength to bring about the chemical reaction. Oxidizing agents of sufficient strength include bleach, chlorine, hydrogen peroxide, brominating and chlorinating agents (the type of chemicals used in swimming pools and spas), dissolved oxygen in combination with certain types of dissolved metal ions (e.g., iron or ferric ions, or “Fenton” type oxidants).

It is expected that all these oxidizing agents are readily present in wastewater discharge lines, sewer lines and in sewer waters. Unlike the metallic mercury in dental amalgam, inorganic mercury is water-soluble and, once formed, becomes readily transportable in the environment.

In addition, dental amalgam in contact with dissimilar metals may generate galvanic corrosion (the so-called “battery effect”). Galvanic corrosion would release mercury from the amalgam thereby making it available for conversion into methylmercury.

Outside the sewer lines, the action of ozone and the combination of oxygen and sunlight can convert metallic mercury into inorganic mercury.
Step 2
The conversion of inorganic mercury to methylmercury is brought about by microorganisms. The most widely studied microorganisms for methylmercury formation are the sulfate-reducing bacteria (SRBs), anaerobes that are important mediators of mercury methylation in many ecosystems. Methylating bacteria can generate methylmercury in both freshwater and marine sediments.

Many other microorganisms can produce methylmercury from inorganic mercury. For example, the gastrointestinal (GI) microorganisms in humans as well as in other mammals can form methylmercury from inorganic mercury.

Source: Scarmoutzos and Boyd (2004), cited with permission.

4.2 Empirical evidence of bioavailability

The transformation of dental mercury to methylmercury is further supported by 30 years of research, including such findings as the following:

Aquarium tests with 1- and 2-summer old salmon (Salmo salar) at the Swedish National Environmental Protection Board (SNV) test lab revealed that granulated tooth amalgam releases mercury into the surrounding water in a form that can accumulate in fish. Test results gave a very uniform picture on this point. With 0.5 g of amalgam added for each litre of water, the content of mercury in the livers of test fish increased up to 60 times the original content after an exposure period of 28 days. The results also showed that the mercury was transferred from the livers of the fish into their musculature (Ekroth 1978).

The capacity of the oral bacteria Streptococcus mitior, S. mutans and S. sanguis to methylate mercury was investigated in vitro. Mercuric chloride and pulverized dental amalgam, respectively, in distilled water were used as sources of mercury. Methylmercury was found in the bacterial cells of all three tested strains. The results indicate that organic mercury compounds may be formed in the oral cavity (Heintze et al. 1983).

Leistevuo et al. (2001) found a correlation between the total amalgam surfaces and organic mercury – presumably as methylmercury (CH₃Hg⁺) derived from oral bacteria biomethylation of inorganic mercury – in saliva. These results are compatible with the hypothesis that amalgam fillings may be a continuous source of organic mercury, which is more toxic than inorganic mercury, and almost completely absorbed by the human intestine.

The concentration of total mercury in stimulated saliva was studied in humans with dental amalgam fillings and in 2 non-amalgam groups. The probability of exceeding the limits of mercury permitted in wastewater increased proportionally as the number of amalgam-filled surfaces increased. The mercury limit for sewage is 0.05 mg/l (= 250 nmol/l) effluent according to the Council of European Communities directive 84/156/EEC. In neither of the non-amalgam groups was this limit exceeded, but 20.5% in the amalgam group exceeded the limit (p < .001). The risk of exceeding the limit increased 2-fold for every 10 additional amalgam-filled surfaces (odds ratio = 2.0; 95% confidence interval = 1.3, 3.3). These results demonstrated that humans, especially in populated areas, can be a significant source of mercury pollutants. As a consequence of mercury release, bacteria may acquire mercury resistance, as well as resistance to other antimicrobial agents, thus resulting in failure of antibiotic treatment (Leistevuo et al. 2002).
The bioavailability and accumulation of mercury from external environmental exposure to mixed, cured, milled, sieved and proportioned dental amalgam was examined in the common goldfish, *Carassius auratus*. The fish were exposed to dental amalgam (particle size range from <0.10 to 3.15 mm) representative of the particle size and distribution of that found in the typical dental office wastewater discharge stream. Mercury was found in several tissues, and generally increased with exposure to higher amounts of dental amalgam. Compared to controls, concentrations in the whole body, muscle and liver of fish exposed for 28 days to the highest concentration of amalgam were 200-, 233-, and 40-fold higher, respectively. This study shows that mercury from an environmental exposure to representative samples of dental amalgam typically found within the dental wastewater discharge stream is bioavailable to fish and may accumulate in internal tissues (Kennedy 2003).

Research was carried out to establish whether monomethyl mercury (MMHg) is present in dental-unit wastewater, and if present, to determine the concentration relative to total mercury. In fact, environmentally important levels of MMHg were found to be present in dental-unit wastewater at concentrations that are orders of magnitude higher than seen in natural settings (Stone *et al.* 2005).

### 5 Socioeconomic cost of dental mercury

While most dental professionals who place mercury amalgams typically charge somewhat less for amalgams than for the alternatives, it is clear from the previous discussion that the full costs borne by the rest of society are high, taking into account the overall environmental health ramifications (Hylander & Goodsite 2006; Maxson 2006a).

Once dental mercury has been used, there are a number of ways to keep it from becoming bioavailable, but each of these techniques comes at a cost. Since it is internationally agreed that the global pool of mercury circulating in the biosphere needs to be greatly reduced (GMA 2002), society’s choice is straightforward – either we are obliged to pay such costs, or we must take the alternative path of preventing mercury from entering the environment.

A list of techniques for preventing dental mercury from entering the environment is presented in Table 3 below, together with approximate costs of implementing these techniques, and their potential for reducing dental mercury releases.

This table demonstrates the range of costs that may be expected to be borne by society for continuing to use mercury amalgams. In comparison, it is unlikely that the cost of phasing out the use of mercury by dental professionals would approach any of the estimates presented in Table 3.
Table 3 – Relative costs of various techniques for reducing releases of dental mercury at different control points

<table>
<thead>
<tr>
<th>Activity</th>
<th>Place and year</th>
<th>Cost* (US$ kg⁻¹ Hg)</th>
<th>Reduction potential</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase recycling of mercury captured by chairside traps in dentistry</td>
<td>Minnesota, estimated 1999</td>
<td>240</td>
<td>Medium</td>
<td>Jackson et al. 2000</td>
</tr>
<tr>
<td>Use amalgam separators at dental practices</td>
<td>USA, estimated 2002</td>
<td>2 000 to 4 000</td>
<td>Medium/Large</td>
<td>Derived from Bender 2002</td>
</tr>
<tr>
<td>Use amalgam separators at dental practices</td>
<td>USA, estimated 2002</td>
<td>8 400 to 17 700</td>
<td>Medium/Large</td>
<td>AMSA 2002b</td>
</tr>
<tr>
<td>Replace dental amalgam fillings at dental clinics</td>
<td>Sweden, estimated 2004</td>
<td>129 000</td>
<td>Large</td>
<td>Hylander and Goodsite 2006</td>
</tr>
<tr>
<td>Remove amalgam fillings before burial or cremation</td>
<td>Sweden, estimated 2004</td>
<td>400</td>
<td>Large</td>
<td>Hylander and Goodsite 2006</td>
</tr>
<tr>
<td>Clean crematoria flue gases with activated carbon</td>
<td>Sweden, estimated 2004</td>
<td>170 000 to 340 000</td>
<td>Medium/Large</td>
<td>Hylander and Goodsite 2006</td>
</tr>
<tr>
<td>Clean crematoria flue gases with activated carbon</td>
<td>UK, estimated 2004</td>
<td>29 000</td>
<td>Medium/Large</td>
<td>Hylander and Goodsite 2006; BBC 2005</td>
</tr>
<tr>
<td>Remove mercury from crematoria gases (cold start furnace)</td>
<td>OSPAR estimate</td>
<td>50 000 to 75 000</td>
<td>Medium/Large</td>
<td>Derived from OSPAR 2003a</td>
</tr>
<tr>
<td>Remove mercury from crematoria gases (warm start furnace)</td>
<td>OSPAR estimate</td>
<td>25 000 to 37 000</td>
<td>Medium/Large</td>
<td>Derived from OSPAR 2003a</td>
</tr>
<tr>
<td>Scrub flue gases of medical waste incinerators</td>
<td>USA estimated 1996</td>
<td>4 400 to 8 800</td>
<td>Medium/Large</td>
<td>US EPA 1997</td>
</tr>
<tr>
<td>Use carbon injection in flue gases of waste incinerators</td>
<td>USA, estimated 1996</td>
<td>465 to 1 900</td>
<td>Medium/Large</td>
<td>US EPA 1997</td>
</tr>
<tr>
<td>Use combined technologies on waste incinerators</td>
<td>Uppsala, Sweden, 2004</td>
<td>40 000</td>
<td>Large</td>
<td>Hylander and Goodsite 2006</td>
</tr>
</tbody>
</table>

Sources: Minor adaptation of Hylander and Goodsite (2006).

6 Observations

The main observations drawn from this analysis may be presented in the form of answers to several key questions.

What is the magnitude of mercury use in dental amalgam?

Dental use is the second largest use of mercury in the EU-27, behind the use of mercury in the chlor-alkali industry, which is under heavy pressure to become mercury-free. It is estimated that EU dental professionals use some 125 metric tonnes of mercury, and place over 200 million mercury fillings each year, while the EU population as a whole carries over 1100 tonnes of mercury in their mouths.

What is the magnitude of mercury releases due to dental amalgam?

In terms of mercury emissions to the atmosphere, emissions related to dental use may well exceed 20 tonnes/year – exceeded in the EU only by coal combustion and chlor-alkali plants (Maxson 2006b). Estimated releases to surface waters of 10-20 tonnes would put dental applications solidly in first place in this category. And with a further 30-50 tonnes released to the groundwater and the soil, dental uses appear to be in close competition with chlor-alkali...
plants (Maxson 2006b) for first place in the EU in terms of total mercury released to the environment.

**What is the environmental problem of mercury in dental amalgam?**

Entirely apart from any question of health effects due to inhalation of mercury vapour from fillings, the use of mercury in dental amalgam is not a controlled use of mercury, despite increasing efforts to implement end-of-pipe emission reduction measures; it is a use that leads to significant dispersal of mercury throughout the environment via wastewater, sewage sludge disposal to land, solid waste incineration, cremation, etc. Furthermore, it has been demonstrated that a certain portion of this mercury becomes bioavailable, and may constitute a significant source of risk to human health and the environment. Dental use of mercury is a major contributor to the global pool of mercury circulating in the environment, which the international community has determined needs to be urgently reduced.

**What is the real cost of mercury in dentistry?**

Especially in light of the wide dispersal of dental mercury in the environment, end-of-pipe mercury removal and environmental cleanup solutions are always far more expensive than preventing releases in the first place. The EU has accepted that it needs to better manage the risk of environmental and health effects due to mercury. Such mercury control and cleanup costs are one indicator of the real costs to society of continued use of mercury in dental fillings.

**Do cost-effective solutions exist?**

Without doubt the most cost-effective and environmentally responsible solution to the dental mercury problem is rapidly phasing out mercury in dental use, for which there are a range of affordable mercury-free alternatives (Keml 2005). The number of dental restorations for which dental professionals might argue that a mercury amalgam is the only viable option are very few in number.

**What are the main barriers to a phase-out of mercury amalgams?**

There is evidence that less than one-third of the general public is aware that mercury is the main component of “silver” fillings, and patients are often not aware of alternative filling materials (MPP et al. 2006). The dental profession, the general public and policy-makers are not well informed about the full costs to society of continued use of mercury in dentistry, its dispersal in the environment, the human health and environmental implications, and the viability of alternative filling materials. As a general rule, EU Member States continue to offer subsidies of mercury amalgams through healthcare system reimbursements, which reinforces their continued use. As a general rule, EU Member States do not adequately manage hazardous dental amalgam wastes, which leads to unnecessary releases to various media. As a general rule, EU Member States have not effectively implemented controls on mercury emissions from crematoria, which leads to unnecessary atmospheric releases. The diverse and serious environmental problems related to mercury in amalgams would be greatly reduced if, in their oversight role, European agencies chose to engage in a more focused effort to encourage Member States to phase out mercury amalgams altogether.
References


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Finland (2005) – Information provided in advance by Finland for the Stakeholder Consultation Meeting 8 September 2005, convened by the European Commission DG Environment.


Scarmoutzos and Boyd (2004) – LM Scarmoutzos and OE Boyd, Environmental and Toxicological Concerns of Dental Amalgam and Mercury, MVS Solutions, Inc. (LMS) and SolmeteX, Inc. (OEB), Massachusetts, USA.


APPENDIX I – Relevant legislation and policies

There are various types of legislation and related measures that deal with different aspects of mercury released from dental applications. These measures all attempt to keep mercury out of the environment, and typically fall within three categories:

- measures with the objective of eliminating the use of mercury, which have the effect of reducing mercury throughout the whole life cycle, including dental releases, crematoria releases, and the global pool of mercury circulating in the biosphere.
- measures that may be adopted by dental practices with the objective of reducing their releases of mercury, such as capture and sequestration of as much mercury as possible, and then hazardous waste disposal or possibly recycling.
- measures that may be adopted by crematoria with the objective of reducing their mercury releases, such as the (admittedly controversial) removal of amalgam fillings prior to cremation, the use of flue gas controls, etc.

A.1 Measures to eliminate mercury from dental care

Sweden and Denmark are perhaps the countries that have advanced the most in eliminating the use of mercury-containing amalgam.

A.1.1 Sweden

The Swedish Chemicals Inspectorate has asserted that there are strong grounds for banning amalgams for environmental reasons, and that from a health perspective there is every reason to apply a precautionary approach (KemI 2004). In 1991 the government began a phasing-out process in which amalgam would cease to be used in dentistry for children and young people from 1 July 1995 and cease to be used entirely by 1997. Through significant cooperation among the National Board of Health and Welfare, Parliament, City Councils, and the Swedish Chemicals Inspectorate amalgam use was significantly reduced, but not eliminated. To make amalgam more cost-neutral as compared to other filling materials, the Swedish Parliament decided in 1999 that no further healthcare reimbursements would be given for amalgam fillings through the national dental insurance plan (KemI 2004). In June 2004 the Swedish Chemicals Inspectorate and the Swedish Board of Health and Welfare proposed that, for environmental reasons, dental amalgam should be covered by a national general ban on mercury (with a few temporary exceptions). It is estimated that only 2-5% of new fillings in Sweden contain mercury (Sweden 2005).

A.1.2 Denmark

In Denmark, which has a national policy of significantly reducing both mercury uses and releases, dental amalgam is allowed only in molar teeth subject to heavy loads and extensive wear. Denmark intends to ban the remaining use of dental amalgam as soon as the Danish National Board of Health is satisfied that the mercury-free alternatives have full substitution capabilities (GMA 2002).
A.1.3 Norway

There is no formal regulation of the use of amalgam in Norway. However, in 1991 the Norwegian Directorate for Health and Social Affairs introduced guidelines to reduce the use of amalgam fillings as a dental restoration material. The new guideline from 2003 stated that filling materials other than amalgam must be considered as the first choice for dental fillings, and that amalgam use should be limited as much as possible in consideration of the environment and possible adverse health effects. Moreover, the use of mercury in dental fillings should be avoided during pregnancy. The consumption of dental amalgam has fallen by approximately 85% since 1990 and represents an ever-decreasing share of the treatment options offered (Norway 2003 and 2006). As noted previously, the Norwegian Pollution Control Authority (SFT) has recently proposed a prohibition on the use of mercury, including mercury in amalgam fillings, based primarily on the harmful effects of discharges of mercury into the environment (Norway 2006).

A.1.4 Germany

Germany's Ministry of Health decided to ban the use of mercury fillings in women and children, following the International Academy of Oral Medicine and Toxicology conference in Düsseldorf in 1992. Members of the dental profession had asked for an opportunity to present evidence with regard to the safety of mercury fillings, and included 25 presenters and two moderators who are experts in mercury. The peer-reviewed conclusions supported the proposed ban on exposure of children and women of childbearing age to mercury from amalgam fillings.

A.1.5 USA

Although there are no national or state regulations requiring such changes, for reasons ranging from health, environmental and liability concerns to patient preferences (including cosmetic reasons), a growing number of dentists in the USA no longer place mercury fillings. According to an informal survey, the percentage of general practice dentists still placing mercury amalgam has declined to 68 percent (CRA 2003). In fact, the number of dentists who pledge not to place amalgam fillings has increased in each informal survey by Clinical Research Associates over the past twenty years, and three national dental societies promote mercury-free dentistry. At the same time, some health insurance companies may reimburse no more than the cost of placing an amalgam filing.

Several states, including California, Maine, Connecticut, and New Hampshire, require dentists to post “fact sheets” about silver fillings in their offices, or to hand out relevant information to their patients. A number of states, including five of the six New England states, New York, New Jersey and Washington also mandate installation and operation of amalgam separators as a way to reduce mercury pollution.

A.1.6 Japan

Japan has (unofficially) discouraged mercury use in dental applications in order to reduce the mercury content of wastewater sludge, and as a consequence of public consciousness

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provoked by the disastrous mercury pollution of the fishing village Minamata 50 years ago. Japan now uses mercury amalgam for less than 4% of fillings nationwide.\textsuperscript{11}

General trends can be further deduced from surveys of teaching practices. In Japan 93% of dental schools were reported to teach the use of alternative materials in preference to amalgam (Eichmiller, 2006).

\textbf{A.2 Measures to reduce mercury releases from dental practices}

\textbf{A.2.1 European Union}

There are diverse pieces of EU legislation that are intended to control general releases of mercury to the environment, such as legislation on incineration of waste; management of hazardous waste; landfill of hazardous, non-hazardous or inert waste; disposal of sewage sludge; discharges of dangerous substances to water; protection of groundwater against pollution caused by certain dangerous substances; etc. With regard to dental amalgam wastes, the most important are those concerning hazardous wastes and wastewater.

The EU Hazardous Waste Directive has determined that dental amalgam is a hazardous waste. The annex of this directive explicitly mentions, among others, the European Waste Catalogue codes 06 04 04 “Waste containing mercury”, and 18 01 10 “Amalgam waste from dental care.” It is generally considered that “environmentally sound management of dental amalgam waste” implies that at least 95% of the mercury content of amalgam waste has to be removed from the waste stream (and managed as hazardous waste), effectively obliging dental clinics to install amalgam separators in order to comply with EU legislation. In fact, even if a dentist no longer places amalgam fillings, he or she will continue to remove them from teeth for many years.

While the Hazardous Waste Directive has been formally transposed to national legislation in most of the EU Member States, as discussed in Section 3.2.1 the number of adequately functioning separators in place in the EU likely remains as low as 20-30%, and the European Commission is known to be encouraging Member States to improve the level of compliance of dental offices and clinics.

\textbf{A.2.2 Norway}

Wastewater and amalgam waste from dental clinics are regulated in Norway. A limit on discharges and a requirement to have an approved amalgam separator (required to remove 95% of mercury from the wastewater) were introduced in 1995. This led to a significant reduction of mercury discharged into municipal sewers – from 350 kg in 1995 to 60 kg in 2003. All waste and sludge containing amalgam must be delivered to appropriate hazardous waste disposal facilities.

\textbf{A.2.3 United States}

The USA has no national legislation that addresses dental mercury waste, although some states are beginning to implement relevant regulations. For example, the Vermont Department of Environmental Conservation (DEC) has issued Dental Best Management Practices (BMPs) and required all dental practices to self-certify compliance with these

\textsuperscript{11} Estimated at 3.7% of the 70 million fillings placed in 1999 (Welfare Statistical Society 2001, as cited in Hylander and Meili 2003).
BMPs as of 31 January 2007. The Vermont BMPs also required dental clinics to install amalgam separators on the dental wastewater discharge system by 1 January 2007, and to properly handle dental amalgam wastes and other hazardous wastes. The amalgam separator requirement is expected to lead to a significant decrease in mercury releases to municipal wastewater treatment plants and systems.

A.3 Measures to reduce mercury releases from crematoria

A.3.1 European Union

According to the European Commission, most of the problem with mercury emitted from crematoria is addressed by an OSPAR Recommendation, and by legislation in some of the remaining Member States who are not parties to the OSPAR Convention (European Commission 2005). The OSPAR Recommendation 2003/4 on Controlling the Dispersal of Mercury from Crematoria covers all EU countries that are party to it (i.e. in Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK, as well as Iceland, Norway and Switzerland). OSPAR Recommendation 2003/4, which does not itself have the force of law, calls for the use of Best Available Techniques (BAT) for controlling mercury emissions from crematoria and briefly describes four types of control technology:

- co-flow filters, using an absorbent for mercury, with capture by a cloth filter,
- a solid bed filter, using absorbents such as cokes or zeolites,
- traditional gas scrubbing techniques, and
- honeycomb catalytic absorbers, using precious metal (gold/platinum) following particulate removal.

However, a recent review of the status of the implementation of the OSPAR Recommendation shows a rather limited application of mercury controls on crematoria emissions among the OSPAR member countries. Based on this report (OSPAR, 2006) it is evident that over 80% of the nearly 1000 crematoria (2006 estimate) in the EU-27 have no or limited emission controls. Less than 15% of the crematoria have controls for other emissions that may or may not reduce mercury emissions. Fewer than 5% of EU crematoria have installed devices specifically for reducing mercury emissions, although more are planned during the next five years, especially with regard to the crematoria doing the most business.

As an example of an EU country with national standards regulating crematoria, the UK established standards in the fall of 2004 (Defra 2004) and then revised them in the spring of 2005 (Defra 2005). The original standard declined to regulate existing crematoria but, for new crematoria, established a mercury emissions limit of 150 milligrams per four cremations, with a further limit of 50 µg/m3 of exhaust gas. In the revised standard, 50% of all cremations at existing crematoria are also subject to mercury emission limits, with a deadline of 31 December 2012. Furthermore, the UK regulations allow for "burden sharing," i.e., instead of each crematorium being obliged to install mercury control equipment, several crematoria can share the cost of abatement equipment so that 50% of all cremations carried out by existing crematoria are within the mercury emission limits.

A.3.2 Norway

Norway’s Pollution Control Authority (SFT) has developed air and water regulations for crematoria, which went into effect on 1 January 2003 for new crematoria, and 1 January
2007 for existing crematoria. The regulations are intended to result in a 95% reduction in mercury emissions from the largest crematoria, according to an SFT news release issued on 15 January 2003. For air the emission limit is 50 µg/m³ of exhaust gas, while for water the limit is 2.0 µg/litre (Reindl 2007).

**A.3.3 Switzerland**

For Switzerland, according to an internet article published in 2003 (Knellwolf 2003, as cited by Reindl 2007), the standard of 0.2 mg of mercury emissions per hour of operation took effect in 1991. Switzerland has estimated that each cremation contributes 3 grams of mercury. The article also noted that of the 59 crematoria ovens only 13 were equipped with air pollution control equipment, and that crematoria operators were selecting those corpses with large numbers of mercury fillings for cremation in the more modern ovens.

**A.3.4 United States**

No crematoria mercury emission standards exist in the US (Reindl 2007). Under Section 129 of the Clean Air Act, the US EPA is required to set standards for a variety of air sources. Originally, standards for crematoria were to be developed by November 2000, and in a Federal Register notice at that time, EPA committed to releasing its standards by 15 November 2005. However, in the Federal Register of 9 December 2004, EPA decided to interpret its mandate differently, and wrote:

"... that the human body should not be labeled or considered ‘solid waste.’ Therefore, human crematories are not solid waste combustion units and are not a subcategory of OSWI for regulations. If EPA or States determine, in the future, that human crematories should be considered for regulation, they would be addressed under other authorities."

**A.3.5 Japan**

There appear to be no formal requirements in Japan that crematoria should be fitted with technology designed specifically to reduce mercury emissions.