Testimony to the
U.S. House Subcommittee on Domestic Policy
Of the Committee on Oversight and Government Reform

"Environmental Risks of Mercury Dental Fillings"

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1 Background

1.1 Domestic Policy Subcommittee request

This paper has been prepared at the request of the Domestic Policy Subcommittee, Oversight and Government Reform Committee, in support of the testimony of Mr. Michael Bender, Director of the Mercury Policy Project, at a hearing on November 14, 2007, 2:00 PM in Room 2154 Rayburn House Office Building.

The hearing concerned the environmental risks due to the release of mercury from dental uses.

Mr. Bender was asked to testify on the significance of dental mercury amalgam as a precursor to methylmercury releases into the environment across the United States. Specifically, he was asked to discuss exposure via the following pathways:

1) incineration of municipal sewage sludge,
2) cremation,
3) all emissions from dental offices (including air releases, accidental spills, contaminated plumbing fixtures and buildings, wastewater discharges and disposal into municipal solid waste and hazardous waste facilities), and
4) direct emissions from sludge application to land and as a soil amendment.

Finally, Mr. Bender was also asked to discuss how dental mercury amalgam may be a factor in the US Environmental Protection Agency's (EPA's) finding that "most [publicly owned treatment works] POTWs will not meet [the mercury] criterion [adopted by Great Lakes states]" and what the consequences may be for mercury contamination of the Great Lakes and the development of total maximum daily loads (TMDL) for the Great Lakes and other bodies of water throughout the United States.

1.2 Mercury in the environment

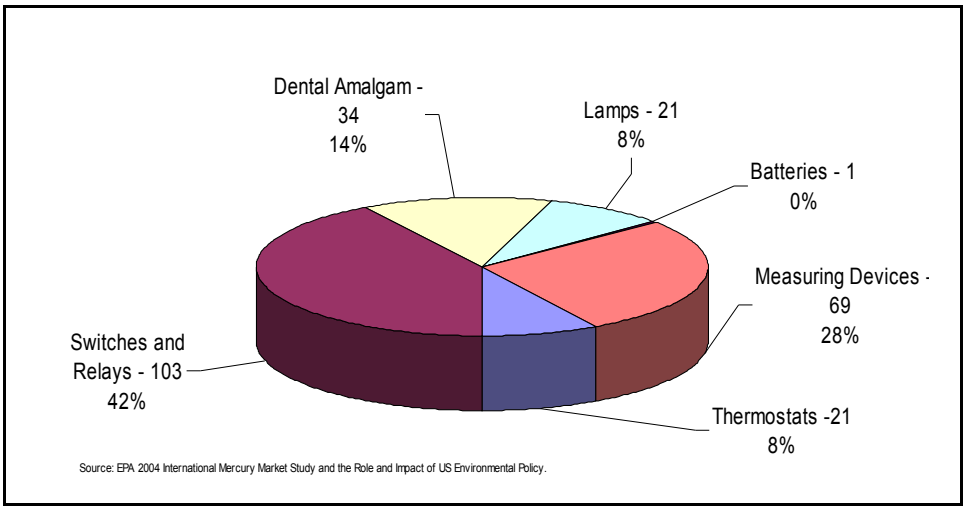
Mercury is a naturally occurring metal and a persistent, bioaccumulative toxin. It enters the environment via natural events, such as volcano eruptions, as well as through human activities. Methylmercury is more mobile and even more toxic than elemental mercury, and it easily finds its way into the food chain, contaminating fish. Methylmercury is synthesized by microbial action on mercury-polluted sediments and soils, and among other sources, is generated as a by-product of the combustion of mercury-containing materials. The release of mercury by combustion occurs in a variety of settings, including coal-fired power plants, municipal incinerators, sludge incinerators, hazardous waste incinerators, industrial boilers, and other industrial processes.

1.3 Mercury in dental amalgam

As shown in the EPA figure below, dental offices are the third largest user of mercury, after wiring device/switch makers and manufacturers of measuring and control instruments.[1]

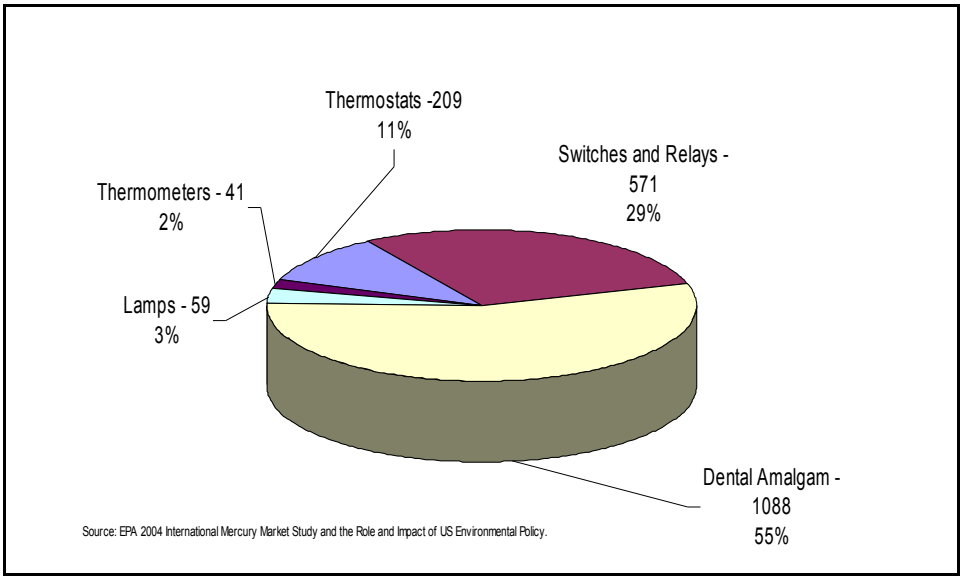
[1] EPA (2006) – Roadmap for Mercury p. 36 (online at http://www.epa.gov/mercury/roadmap/htm).

Figure 1 – Mercury consumption in the USA



Furthermore, as seen in the following EPA figure, mercury contained in the existing dental fillings of Americans comprises over half of all mercury "circulating in the economy" today, amounting to over 1000 tons.[2]

Figure 2 - Mercury circulating in the U.S. economy



Dental amalgam is a large source of mercury waste in the environment. According EPA, "Mercury discharges [in wastewater] from dental offices far exceeded all other commercial and residential sources."[3] EPA cited an estimate that 36 percent of mercury reaching municipal sewage treatment plants is released by dental offices. Other investigations have put the figure closer to 50 percent (NEG-ECP 2007).

[2] EPA 2004 International Mercury Market Study, as cited in Mercury Policy Project, "Current Status of US Dental Mercury Reduction Initiatives" (Oct. 12, 2007)
[3] Roadmap *op. cit.*, p. 8

Mercury from dental amalgams is a significant source of airborne emissions, although data concerning precise quantities emitted are unavailable. EPA has estimated airborne mercury attributable to wastewater sludge incineration to be 0.6 ton per year, but the following discussion demonstrates that this figure is seriously underestimated. EPA emissions estimates do not include total mercury emitted during the cremation of human remains. However, cremation is also a significant source of emissions, due to the large amount of mercury in existing dental fillings. The largest source of airborne mercury is coal-burning power plants, which emit an estimated 48 tons of mercury per year.

1.4 Key issues re health risk via fish consumption

The effects of mercury exposure on human health and wildlife are driving a number of efforts to significantly reduce the level of this toxic, persistent, and bioaccumulative metal in the environment. Exposure to mercury, a neurotoxin, affects the brain and nervous system. The consumption of fish from waters contaminated with mercury offers the greatest risk of exposure to this pollutant (NACWA 2002).

Due in part to the EPA's human health criterion for methylmercury in fish tissue and the increasing number of fish advisories based on mercury, new mercury effluent limits are being imposed throughout the United States (Special Initiatives - NACWA Mercury Initiatives, http://www.nacwa.org/index.php?option=com_content&task=view&id=64&Itemid=72). In addition, increased monitoring of mercury in the water column and fish tissue, and the application of more stringent standards[4] has led to increasingly stringent mercury effluent limits in National Pollutant Discharge Elimination System (NPDES) permits, as authorized by the Clean Water Act.

As of 2001, approximately 6% of the major publicly owned treatment works (POTWs) in the United States had NPDES permits with mercury effluent limits and approximately 10% of the major POTWs had monitoring requirements (Morris, 2001). Of the agencies with limits, several (particularly in the Great Lakes region) have limits based on the Great Lakes Initiative (GLI) Wildlife Criteria (i.e., 1.3 ng/L), and have had difficulty meeting these limits (EPA 2001).

As more monitoring for mercury is conducted, the number of agencies with effluent limits imposed is likely to significantly increase. The National Association of Clean Water Agencies (NACWA) attributes this development, in part, to new analytical methods and sampling techniques that enable clean water facilities to measure levels of mercury that were previously undetectable (Special Initiatives - NACWA Mercury Initiatives, http://www.nacwa.org/index.php?option=com_content&task=view&id=64&Itemid=72).

Among other issues, the following analysis describes the links between environmental releases of dental mercury and methylmercury in fish.

[4] Ranging from the California Toxics Rule (CTR) Saltwater Criterion (25 ng/L) to the proposed Maine Criteria (0.2 ng/L)

2 Mercury use in dental applications

Recent estimates of mercury use by the dental profession, entirely for amalgam fillings, range from 30 to 44 tons.[5] Within that range, the EPA figure of 34 tons is believed to be a reliable estimate.

The American Dental Association (ADA) has estimated that US dentists place some 100 million fillings per year. While less than 50% of these are now amalgam fillings (approx. 580mg Hg per filling), the majority of old fillings removed are amalgam, leading to the release of large amounts of amalgam waste.

Following the methodology used by Cain et al. (2007), of the 34 tons of "new" mercury consumed in a typical year by dental clinics, some amalgam is carved away or otherwise lost during a typical clinical procedure – averaging some 20-25% of the total amalgam. However, most of the mercury lost to discharge is not the amount of new amalgam lost due to "carving" but the amount of old amalgam that is removed to make room for the new filling. Considering that about 70% of fillings are replacements, that not all fillings are amalgams, etc., some 31 tons of mercury are calculated to go to emissions and waste.

The quantities of mercury consumed and mercury wastes generated by the dental profession are directly related to the average life of a filling. 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 a 1995 article in a Swiss dental medical journal reported the average life to be 10 years. Other estimates have ranged as high as 10-20 years (Reindl 2007).

3 Mercury wastes from dental applications

It should be noted that this section of the report discusses the types of mercury wastes and releases from dental practices, while Section 4 deals more specifically with the quantities of mercury involved.

3.1 Pathways to the environment

The primary sources of mercury waste that originate in the dental clinic include 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.

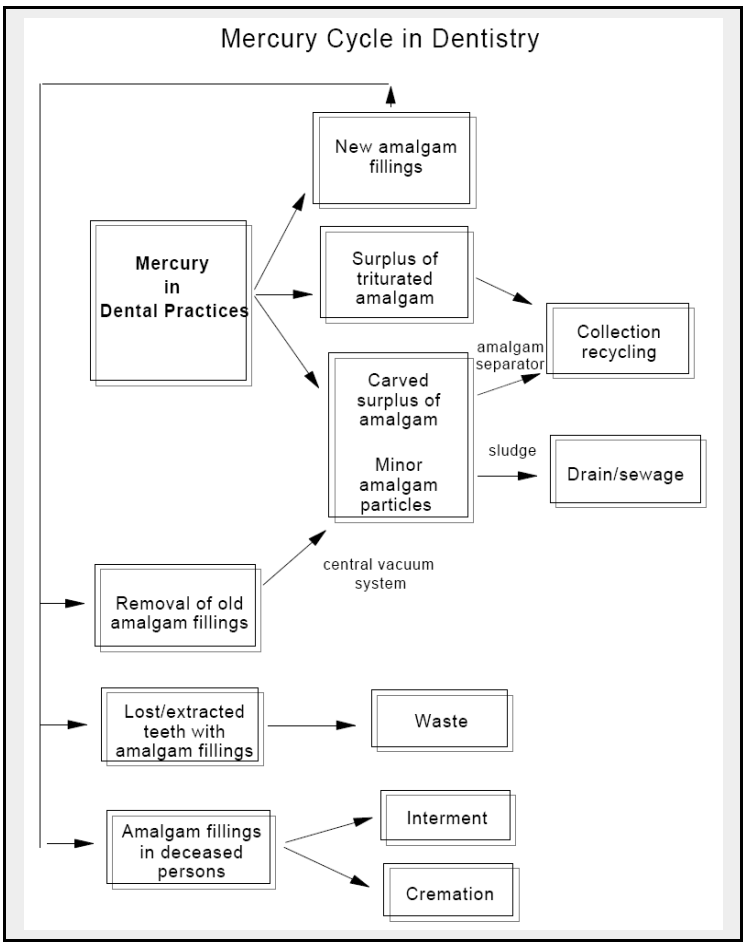
Most dental mercury waste results from the removal of previous fillings from patients' teeth. Together with waste from new fillings, removed teeth, etc., these dental wastes typically follow several main paths. They may be captured for subsequent recycling or disposal, they may be washed down drains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

Figure 3 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

[5] Environ estimated 32 tons for 2004; B. Lawrence, a recycler, estimated 44 tons for 2001; the US EPA estimated 34 tons for 2004; 30.4 tons were reported by manufacturers to the IMERC database for 2004;etc.

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 subsequent analysis.

Figure 3 - General flow of mercury through the dental clinic



Source: Horsted-Bindslev *et al.* 1991 (as cited by Wisconsin Mercury Sourcebook 1999)

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 available that can remove over 95% of the mercury from wastewater.

Dental mercury may enter the environment from a number of paths. For example, if a mercury-containing item is discarded as municipal waste, some mercury may eventually be released into the atmosphere from landfill emissions, or the mercury may vaporize if the waste is incinerated. If mercury passes any filtering devices and enters the wastewater system, most mercury will typically adhere to the wastewater sludge, where it has the potential to volatilize when the sludge is disposed of. Mercury is able to evaporate easily, especially as the temperature increases, after which some is deposited locally and the rest travels through the atmosphere in a vaporized state (Wisconsin Mercury Sourcebook 1999).

Once mercury is deposited into lakes and streams, in the open ocean, or even on land, 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).

3.2 Wastewater releases

3.3 Municipal wastewater system

It is commonly accepted that most municipal wastewater systems encounter significant levels of mercury, and it has been determined that typically close to 50% of that mercury originates from dental practices (AMSA 2002a). Some observations are summarized in the table below.

City	Mercury load from dental offices
Duluth, Minnesota	36%
Seattle, Washington	40-60%
Palo Alto, California	83%
Greater Boston Area, MA	13-76%

The quantity of mercury going to wastewater systems from dental clinics is difficult to quantify, but it should be noted that most municipal wastewater treatment systems are not designed to treat or remove mercury from the wastewater stream. In fact, it is economically far preferable to keep mercury from reaching the wastewater plant.

Most of the mercury entering the wastewater stream will concentrate in the sewage sludge or “biosolids,” and the rest will be discharged to downstream surface waters along with the treated effluent. If a wastewater treatment plant incinerates its sludge, and operates with a wet scrubber system, mercury from amalgam may be carried back to the headworks of the treatment plant. Therefore, mercury that came into the plant as an amalgam waste may later be discharged to a receiving water as another form of mercury (no longer amalgam).

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

3.3.1 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 attaches itself to the inside of metallic pipes. The slow dissolution and re-release of this mercury is often sufficient, even after dental clinic emissions have been greatly reduced, to exceed wastewater discharge standards, and then serves 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 during more recent work in a Swedish dental clinic (Hylander *et al.* 2006a). These studies indicate that serious maintenance work on a dental clinic wastewater system should ensure that all pipes and plumbing fixtures are cleaned and/or replaced since they can constitute an ongoing source of mercury releases.

3.3.2 Septic tanks

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

3.4 Solid waste generated

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

3.4.1 Municipal landfill and incineration

Despite regulations regarding the characterization 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 volatilize 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 and undetectable.

3.4.2 Hazardous waste landfill and incineration

The regulations for hazardous waste treatment are normally 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 minimize 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.

3.5 Air emissions at the dental clinic

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

3.5.1 Air emissions during dental work

Dental personnel may be exposed to the following sources of mercury vapors: "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).

3.5.2 Air emissions from the dental clinic wastewater system

As already mentioned, dental clinical procedures generate mercury wastes, slurry and fine particulate and dissolved matter from mercury amalgam filling materials. Some 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 vapor, either into the atmosphere outside the dental clinic or into the wastewater system, depending on the type of equipment used (Rubin and Yu 1996).

3.6 Infectious waste treatment

A survey in 2000 found that 25-30% of dentists disposed of some of their dental amalgam waste as infectious waste due to the potential presence of pathogens (KCDNR 2000). Typically infectious waste is disposed of by "autoclaving" and landfill, which may as well result in some mercury vapor releases, discharge of effluents to the wastewater system, etc. (HCWH 2002).

3.7 Recycling

Recycling of dental amalgam wastes is increasing, although less than 5% of the nation's dentists use amalgam separators today. This is a logical way to deal with large amounts of amalgam waste with a high mercury content, and the high-temperature retorting process employed by recyclers is also able to address concerns about pathogens in the amalgam wastes.

The recycling process also generates some air emissions of mercury, but these are generally low. Some stakeholders are concerned about the fate of the mercury after recycling, noting that it may end up being sold for use by artisanal gold miners, or the manufacture of products or other applications that are associated with significant and/or diffuse mercury releases.

3.8 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. Given the relatively few state clean-out programs conducted nationwide, it may be assumed that there remain some 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.

3.9 Burial

Amalgam fillings may continue to release mercury 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 scarce and expensive, cremation is becoming more common.

3.10 Cremation

As mentioned above, cremation is a more and more common practice in the US, as the cost of burials increases over time. Cremation is typically carried out at a high temperature that vaporizes virtually all of the mercury in any dental amalgams, although it has proven quite difficult to balance the amount of mercury present 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 for a time to internal parts of the flue gas system. Often crematoria are located within cities and close to residential areas, and stacks tend to be relatively low (UNEP 2003).

4 Air emissions related to the use of dental mercury

It should be noted that this section of the report focuses largely on the quantities of mercury wastes and releases from dental practices, while Section 3 above deals more specifically with the types of mercury wastes and releases generated.

4.1 Estimating waste mercury quantities and pathways

It is frequently assumed by those developing estimates of mercury flows that all processes operate in a similar manner to certain ones that may have been studied or measured. However, it is especially evident in dealing with mercury flows, which traverse virtually the gamut of water, land, waste, and air emission and disposal issues, that this is not the case. For example, some mercury waste is still incinerated in burn barrels or discarded in unauthorized landfills, septic systems operate where wastewater systems are unavailable, wastewater “exceptions” and overflows are common, and dental clinics face a range of challenges in the proper installation and maintenance of separators. In these and related instances, substantial dental mercury wastes continue to be discarded to the municipal waste system, etc.

As in the chlor-alkali industry, another large mercury user, even if only 10-20% of the facilities operate in a substandard manner, it is enough to greatly influence the quantities of mercury otherwise assumed to be following various pathways. This must be kept firmly in mind when modeling mercury flows.

4.2 Municipal wastewater and sewage sludge

4.2.1 Quantities generated, and dental contribution to POTW Hg burden

US EPA has estimated the total quantity of mercury in sewage sludge at about 15 tons per year,[6] and the Association of Metropolitan Sewerage Associations (AMSA) has estimated

[6] Statement of Geoffrey Grubbs, Director, Office of Science and Technology, U.S. Environmental Protection Agency, before the Subcommittee on Wellness and Human Rights of the Committee on Government Reform, United States House of Representatives, October 8, 2003.

the dental contribution to that at just under 7 tons of mercury (AMSA 2002b). Scarmoutzos and Boyd (2004) have estimated the dental mercury contribution to sewage sludge at 6-12 tons. According to a Jan 2006 white paper by the National Assoc. of Clean Water Agencies (formerly AMSA), "the ADA [American Dental Association] estimates that 50% of the mercury entering POTWs is from dental offices."[7] NESCAUM (2005) concurs with this observation.

Miniscule but constant releases from mercury amalgams are ingested and then excreted by the human 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. Research has shown that the 74% (or approximately 6.3 million persons at the time of the study) of the population in Sweden with amalgam fillings continuously released over 200 lbs Hg/year to the wastewater system simply by chewing, swallowing and excreting (Skare and Engqvist, 1994; Kemi, 2004). Based on this research, the US population could well emit 1.5-2 tons Hg/year to wastewater from this source, which would be included in the sewage sludge calculation above.

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), it is estimated that some 40-50% of the mercury not captured by separators or disposed of as solid waste goes into the municipal wastewater system. Based on the above, and referring to the methodology of Cain et al., the quantity of dental mercury entering the municipal wastewater system, including 1-1.5 tons from human wastes, is estimated at over 9 tons, of which just over 90% may be retained in wastewater treatment sewage sludge under normal operating conditions.

The total dental mercury going to wastewater treatment plants may therefore be estimated at about 8.5 tons.

4.2.2 Sewage sludge disposal

According to Cain et al. (2007), about 20% of sewage sludge is incinerated, some 60% is spread on agricultural and other land, about 15% is landfilled, and the rest is disposed of in other ways.[8] Each of these disposal pathways leads to some air emissions, the most important of which are sludge incineration and volatilization of mercury from land applications.

With regard to the quantities of sewage sludge that are incinerated, Cain et al. (2007) estimate that some 60% of the mercury goes to the atmosphere, which would imply close to 1.5 tons of emissions related to dental mercury. However, the figure could be somewhat higher. While the performance of different facilities may be expected to vary widely, data from testing of coal-fired utility emission controls suggests that the scrubber controls typically found on SSIs may capture no more than 20-30% of the mercury. The rest of the mercury ends up in incinerator residues and is mostly spread on the land.

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[7] See http://www.nacwa.org/images/stories/public/2006-01dmercwp.pdf.

[8] The mercury content in sewage sludge, while quite variable, is typically considered tobe in the range of 1-3 mgHg/kg dry weight (AMSA 2002b).

Therefore, there is no doubt that the EPA estimate of 0.6 ton mercury emissions from SSI significantly undercounts sludge-related mercury pollution.[9] A report from the Northeast States for Coordinated Air Use Management (NESCAUM 2005) has calculated, based on measurements, that sewage sludge incinerators (SSIs) in the Northeast US release 543kg, or about 1200 pounds, of mercury per year, and they estimate that half of that quantity is from dental mercury. The NESCAUM region has only 8% of the US population, but a higher per capita concentration of SSIs than the rest of the US, implying that a higher percentage of sewage sludge is incinerated in that region than the US average. After accounting for these differences, if the NESCAUM observations are extrapolated to the rest of the US, they imply SSI air emissions of "dental" mercury of about 2 tons nationwide.

Furthermore, since nationwide about 20% of sewage sludge is incinerated on average, and 60% of the mercury content is assumed to be emitted to the atmosphere (Cain et al. 2007), this implies total mercury in sewage sludge of some 17-18 tons, with a dental mercury content in the order of 8.5 tons.

Carpi et al. (1997) have calculated that the 800,000 acres of land amended with municipal sewage sludge may release 15-18 pounds of mercury per day into the atmosphere, especially during the warm summer months. These releases, as well as smaller releases from sludge disposed to landfills, etc., amount to some 0.8 tons per year released to the atmosphere just from the application of sewage sludge to land, assuming about 50% of the contribution is due to dental mercury.

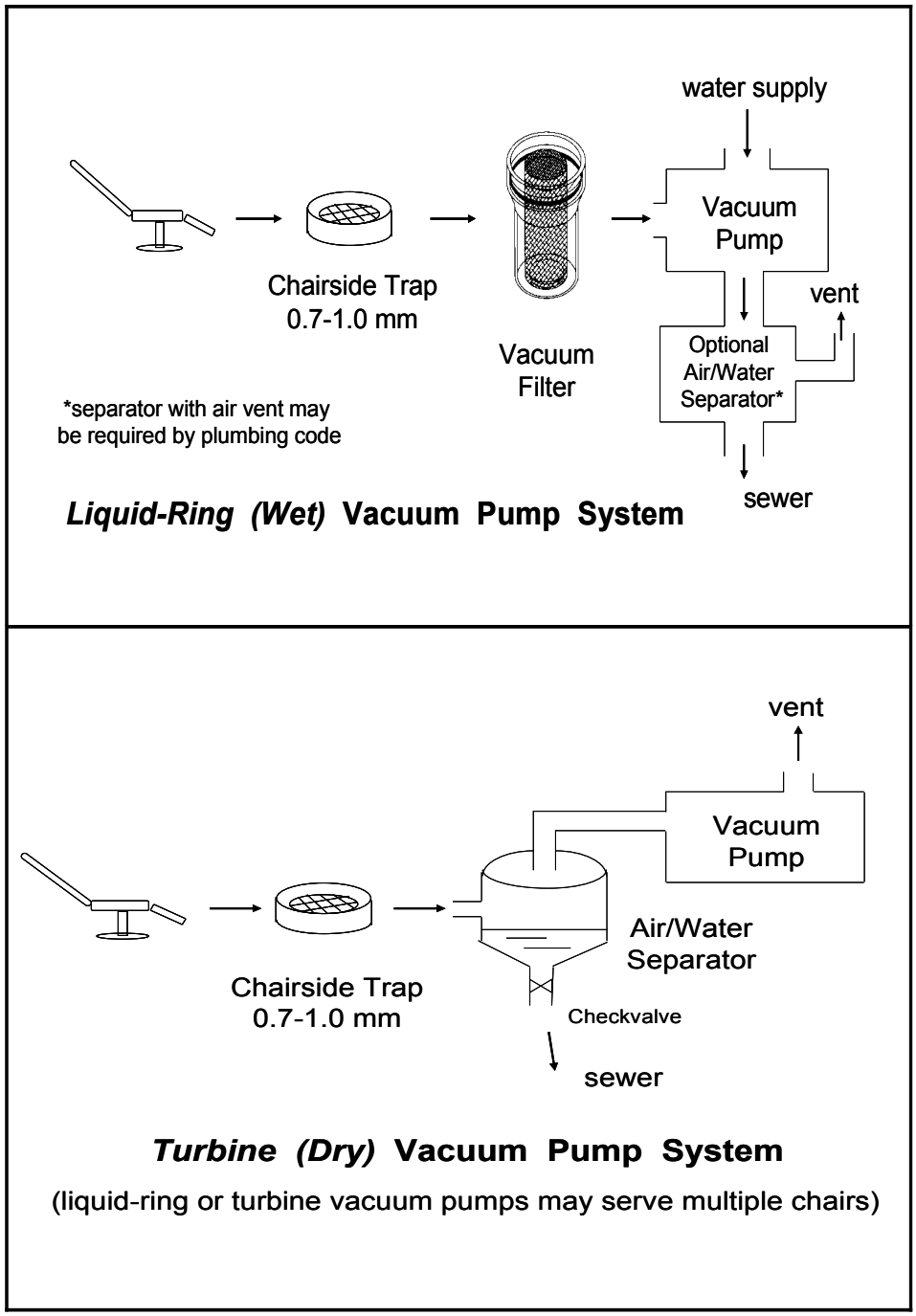
4.2.3 Amalgam separators

Through the use of amalgam removal systems such as chairside traps/meshes, vacuum filters and separators in the wastewater stream, dental clinics may theoretically remove 95-99% of the mercury. In practice, however, waste mercury removal devices may be missing or improperly maintained. Moreover, an industry source has reported that at present probably less than 5% of dental clinics are equipped with amalgam separators. Therefore, the average level of amalgam removal from the dental clinic wastewater system is much lower than the theoretical level cited.

Figure 4 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 80-90% total mercury removal may realistically be achieved if the system is properly maintained. However, a 1998 Swedish study found that one in four separators installed in dental clinics in Stockholm did not operate correctly (due to incorrect installation, blockages or inadequate maintenance), leading to excessive discharges, and more recent investigations have discovered that problems persist (Hylander *et al.* 2006a, 2006b and personal communication).

[9] EPA has admitted that its mercury emission data for sludge incineration is poor, a deficiency it attributed to both the small number of facilities tested and the fact that these facilities were not a random sample of the industry. Emission Factor Documentation for AP-42 Section 2.2, Sewage Sludge Incineration, Office of Air Quality Planning and Standards, EPA, pp. 3-5 and 4-98 (July 1993) (online at http://www.epa.gov/ttn/chief/ap42/ch02/bgdocs/b02s02.pdf).

Figure 4 - Typical dental clinic waste flow systems (without amalgam separator)



Source: Adapted from Berglund (2005).

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 to the air from the wastewater system at about 60 mg/day per dentist. The number of dentists range from 133-175 thousand (AMSA 2002b; Scarmoutzos and Boyd 2007), suggesting over 2 tons air emissions. The methodology used by Cain et al (2007) suggests total air releases directly from dental clinics at just under one ton.

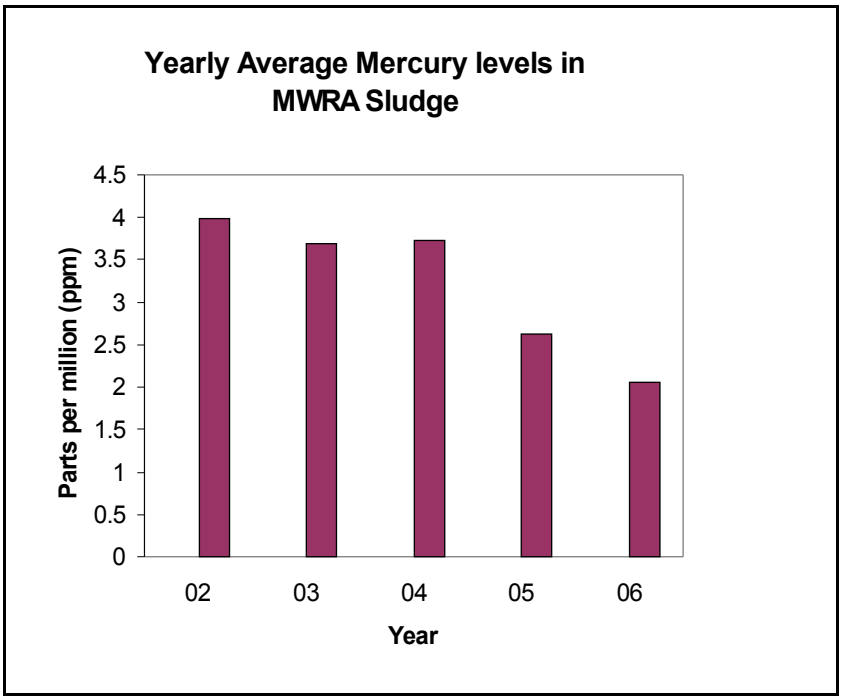
In the EU overall, legislation requiring "environmentally sound management of dental amalgam waste" is considered to imply that at least 95% of the mercury content of amalgam waste has to be removed from the waste stream (and managed as hazardous waste), effectively obliging dental clinics to install amalgam separators in order to comply with EU legislation. However, as already discussed above, there is evidence that the number of dental clinics in the EU with properly functioning separators remains well below 50% (Maxson 2007). 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).

Problems that have been mentioned with regard to amalgam separators include difficulty in getting information about the number of clinics that have actually installed separators; confusion among definitions of traps, filters, separators, etc., in assessing compliance; limited inspection of dental clinics to ascertain the level of compliance; the lack of 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 mercury removal efficiency and actual efficiency; and last but not least, what to do with the amalgam wastes once they have been collected/separated.

Despite difficulties mentioned above, the use of amalgam separators is highly cost effective in preventing releases of mercury to the environment, particularly when compared to the cost to remove mercury at a wastewater treatment plant of approximately $21 million per pound, or $46,000 per gram (AMSA 2002b).

In Norway amalgam separators have been mandatory for dental clinics since 1995, greatly contributing to an enormous reduction in mercury discharged into municipal sewers – from 350 kg in 1995 to 60 kg in 2003.

Recent data from the Boston area Metropolitan Water Resources Authority (MWRA) (see figure below) showed a 48% reduction in mercury concentration in sludge as amalgam separator use increased from less than 20% to over 80%. Additional data is being collected and assessed to evaluate whether these reductions are typical across the region, and to estimate the overall regional reduction in mercury releases attributable to these programs (NEG-ECP 2007).



Source: NEG-ECP 2007

4.2.4 Voluntary vs. mandatory separators

The American Dental Association (ADA) now recommends that amalgam separators be installed in all dental offices, but they maintain that adequate levels of compliance can be achieved through a voluntary program. While there are multiple and complex factors that may influence the success, or lack thereof, of a voluntary program, there is a growing body of evidence that a mandatory approach, while administratively more demanding, is necessary to achieve a faster and more comprehensive result, and even more importantly, to create a level playing field that does not discriminate against the vast majority of dentists who wish to comply with the ADA recommendation to install separators.

King County in Seattle may be taken as an example. King County employed three distinct strategies to limit or control the amount of mercury discharged from dental offices over the 13-year time frame of this case study. The initial resistance of the ADA and dental community to installing separators contributed to the length of time and the changing strategies that had to be employed by the county. The King County Program 1995-2000 focused on an intensive outreach program for dentists including an annual poster, monthly ads in a local journal, a Voucher Incentive Program, EnviroStars, information dissemination, and trade shows/mercury roundups.

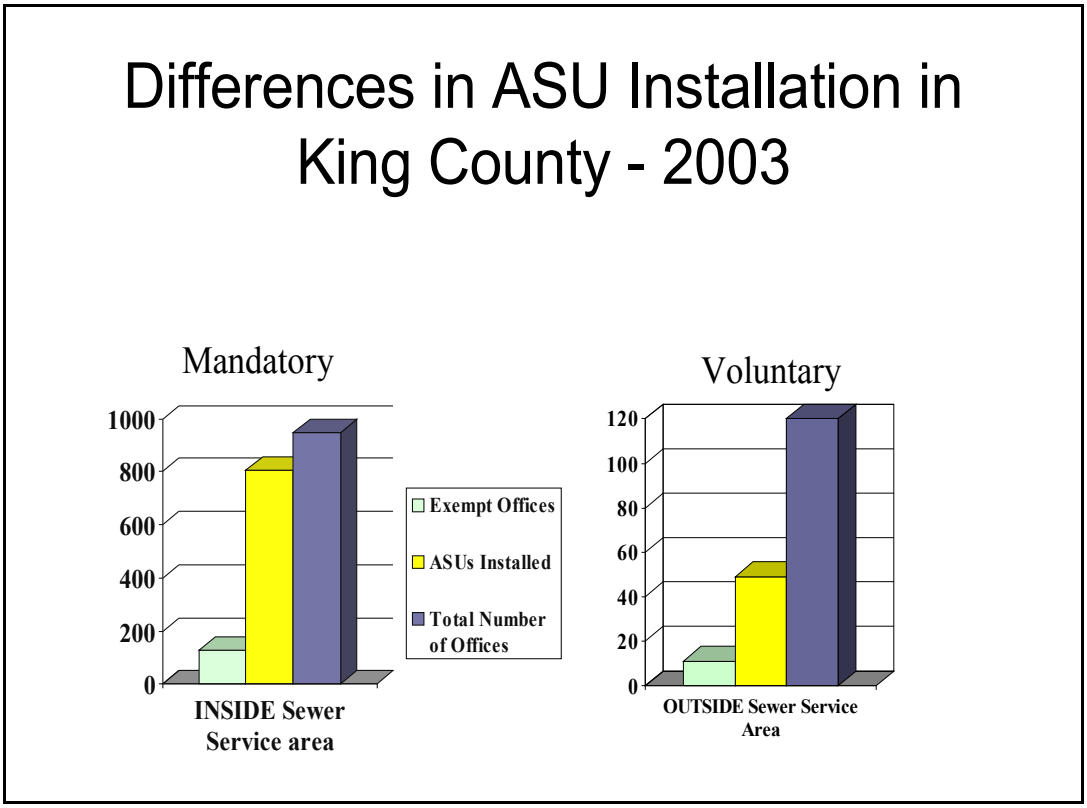
Even after these efforts a 2000 study in King County found that more than three-quarters of dental offices did not recycle or sequester mercury-bearing waste captured in chairside traps and vacuum pump filters. Rather, they put it in the waste bin, included it with medical waste, stored it onsite for eventual disposal or flushed it down the drain (Savina 2003).

As a result, the following practices were made mandatory by July 1, 2003:

- Use best management practices (BMPs) for amalgam waste;

- Demonstrate compliance with K.C. Local Limits (0.2 mg/l) for mercury discharge to sewer (0.1 mg/l for > 5000 gpd, and 0.2 mg/l for < 5000 gpd). These limits are achievable for dental offices with adequate amalgam separators.

The following figure demonstrates the difference in compliance by 2003 in King County between an area with mandatory requirements and an area without, despite the fact that the county's outreach program was targeted at the entire county. By 2005 there was a 97% compliance rate in the King County sewer service area – where separators are mandatory.



For these reasons, a growing number of states have opted for a mandatory requirement for amalgam separators in dental offices, either through law or regulation, as presented below.

- **Connecticut (2003)**
- **Maine (2005)**
- **Massachusetts (2006)**
- **New Hampshire (2006)**
- **New Jersey (2009)**
- **New York (2008)**
- **Rhode Island (2007)**
- **Oregon (2011)**
- **Vermont (2008)**

4.2.5 Dental mercury in municipal solid waste

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).

Based on the Cain et al. (2007) methodology, 9.5-10 tons of dental mercury likely end up in the municipal waste stream each year, of which about 20% is assumed to be incinerated, with most of the remainder going to landfill.

4.3 Cremation

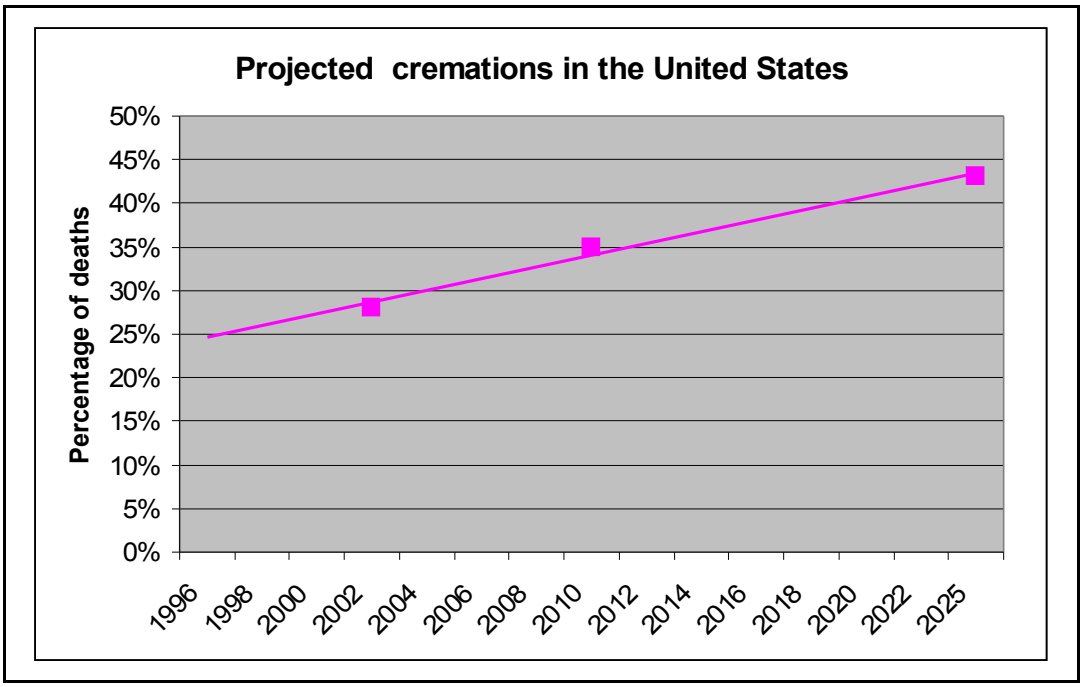
According to the Cremation Association of America, there are about 1,900 crematoria in the US. Nationally, over 30% of Americans are now cremated, a figure that is anticipated to rise to 43% by 2025. The 1998 Northeastern States Mercury Study estimated that each person cremated had an average of 2.9 grams of mercury in fillings, and this figure is still widely considered to be in the right range. (Reindl 2007)

Cain et al. (2007) have estimated that about 3.3 tons of mercury were emitted by crematoria in 2005. In the model used, 25% of these emissions were assumed attached to particulates, which would settle to the ground locally and be classified as land deposition, and 75% assumed to be elemental mercury emissions to the atmosphere. Based on a literature review including ground deposition studies in New Zealand and Norway (Reindl 2007), it appears justifiable to allocate up to 90% of the mercury entering crematoria as emissions to the atmosphere, with some of the balance retained, at least temporarily, in combustion equipment and the stack.

In the next 15 years, emissions from crematoria are expected to rise considerably. There are two simultaneous trends contributing to this: a rise in the average number of fillings per person cremated (better dental health care has resulted in the retention of more teeth, and more fillings, as people age), and a rise in the number of cremations. This will only eventually be counter-balanced by the gradually increasing replacement of amalgam fillings with mercury-free alternatives.

Figure 5 provides an indication of US cremation trends and projections to 2025.

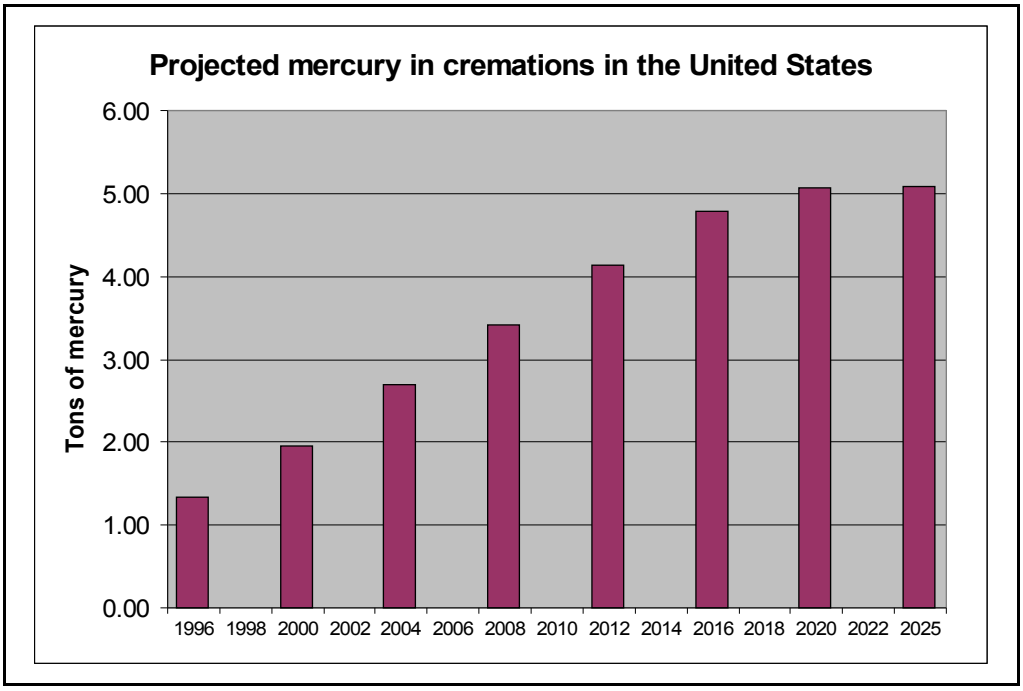
Figure 5 – Projected cremations in the USA (1996-2025)



Source: Derived from CSGB 2004; Reindl 2007.

Figure 6 demonstrates how the increasing number of cremations combines with the increased retention of teeth per person cremated to magnify the quantities of mercury potentially released during cremations.

Figure 6 – Rapidly increasing quantities of dental mercury to be dealt with by crematoria



Source: P. Maxson projections based on data in Reindl (2007)

4.4 Summary of dental mercury atmospheric emissions

The 2002 EPA National Emissions Inventory (version 3) gave atmospheric emissions related to dental mercury as in the first column of the table below. The EPA numbers are compared with those presented in this report, summarized in the second and third columns, which are given as ranges of emissions for the main categories of emission related to dental uses of mercury.

Atmospheric emissions of dental mercury (tons)			
Pathway	**EPA National Emissions Inventory 2002**	**This report 2005 (low estimate)**	**This report 2005 (high estimate)**
Human cremation	0.3	3.0	3.5
Dental clinics	0.6	0.9	1.3
Dental mercury sewage sludge incineration	0.6	1.5	2.0
Dental mercury sludge spread on land and landfilled	n.a.	0.8	1.2
Dental mercury MSW incineration and landfill	n.a.	0.2	0.5
Dental mercury infectious and hazardous waste	n.a.	0.5	0.7
Human respiration	n.a.	0.2	0.2
Total	**1.5**	**7.1**	**9.4**

5 Dental mercury releases increase methylmercury exposures

5.1 Mechanisms of bioavailability

There has been some debate concerning the extent to which mercury released from dental uses may be transformed into methylmercury – thereby becoming “bioavailable” and susceptible to eventual uptake in the food chain. It has been shown above that dental mercury contributes significantly both to the atmospheric burden, from where it eventually deposits on the soil and in waterways, and it is also released directly to waterways.

The main environmental and health impacts of dental mercury releases are due to the bacteriological transformation of inorganic mercury to the highly toxic compound methylmercury, as described in the box below. It has been well established that as dental

mercury releases increase the load of mercury to both the local and global environment, they also increase human exposures to methylmercury through the fish that people eat (US EPA, 1997).

Environmental conversion of dental amalgam to methylmercury in water

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.

5.2 Empirical evidence of bioavailability

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

5.2.1 Environmental and Animal Studies

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 liter 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 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).

It has been demonstrated that the routine application of municipal sewage sludge to cropland significantly increases both total and methyl mercury in the surface soil (Carpi et al. 1997).

5.2.2 Human studies

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 (CH_3Hg^+) 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).

6 Dental contribution to mercury contamination of the Great Lakes and other water bodies

Under the US Clean Water Act, states are required to develop a total maximum daily load (TMDL) estimate for mercury pollution for impaired water bodies. A TMDL can be defined as the sum of the individual waste load allocations (WLAs) for point sources of pollution, plus the load allocations (LAs) for non-point sources of pollution, plus the contribution from background sources of pollution. It can be expressed in terms of either mass per time, toxicity, concentration, a specific chemical, or other appropriate measure. In essence, A TMDL is a calculation of the maximum amount of a pollutant from all sources that a water body or group of water bodies can receive and still meet applicable water quality standards, in this case fish that are considered safe to eat. To comply with this requirement the New England states and New York completed a draft regional TMDL for mercury that was released on April 11, 2007. This TMDL concluded that anthropogenic mercury inputs to the region's freshwater water bodies will need to be reduced between 86 and 98 percent to restore the contaminated fisheries and lift the consumption advisories now in place (NEG-ECP 2007).

If one considers dental mercury releases compared to all other mercury releases to wastewater treatment plants, as discussed previously, the contribution is somewhere very close to 50%. This should raise a warning, especially as an uncertain but very real rate of methylation takes place under a variety of circumstances. Likewise, it has been shown that dental mercury also contributes some 50% of the mercury load to land areas where it is applied, with further opportunities for methylation and releases.

If one looks only at dental mercury atmospheric emissions compared to total US atmospheric emissions, the present contribution may be in the range of 10%. However, if we keep in mind that coal-fired power plant emissions are slated to be reduced by 70-90% in the relatively near future, we can see that dental mercury emissions will soon comprise a far greater percentage of the total. Therefore, with or without reductions from coal-fired power plants, dental mercury discharges will have to be significantly reduced in order to meet stringent TMDL requirements under the Clean Water Act.

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