Cost-Effectiveness of Removing Amalgam From Dental Wastewater

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ABSTRACT

Mercury in the form of amalgam is commonly introduced into dental wastewater as a result of amalgam placements and removals. Dental wastewater is primarily discharged to municipal sewers that convey industrial and residential wastewater to publicly owned treatment works (POTWs) for treatment prior to discharge to surface waters. In some localities, the sewage sludge generated by POTWs from the treatment of wastewater is incinerated, resulting in the emission of mercury to the atmosphere. Some of the mercury emitted from the incinerators is deposited locally or regionally and will enter surface waters.

An assessment was conducted of the use of mercury in amalgam in California and the discharge of that mercury from dental facilities to surface waters via the effluent from POTWs and air emissions from sewage sludge incinerators (SSIs). The annual use of mercury in amalgam placements conducted in California was estimated to be approximately 2.5 tons. The annual discharge of mercury in the form of amalgam from dental facilities to POTWs as a result of amalgam placements and removals was estimated as approximately one ton. The discharge of mercury to surface waters in California via POTW effluents and SSI emissions was estimated to total approximately 163 pounds. A cost-effectiveness analysis determined that the annual cost to the California dental industry to reduce mercury discharges to surface waters through the use of amalgam separators would range from $130,000 to $280,000 per pound.

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Table 1

Overview of Geographic Regions

Northern California		Southern California
Alameda	Northern California	Central Coast
Berkeley	Redwood Empire	Harbor
Butte-Sierra	Sacramento	Kern County
Contra Costa	San Francisco	Los Angeles
Fresno-Madera	San Joaquin	Orange County
Humboldt	San Mateo	San Diego
Marin	Santa Clara	San Fernando
Mid-Peninsula	Southern Alameda	San Gabriel
Monterey	Stanislaus	Santa Barbara-Ventura
Napa-Solano	Yosemite	Tri-County
		Tulare-Kings
		Western

malgams have been the primary restorative material used by dentists in the United States for more than 150 years, and have historically contained approximately 50 percent by weight mercury.[1,2] Mercury in the form of amalgam is commonly introduced into dental wastewater during amalgam placement and removal procedures. Due to the growing concern regarding mercury as a persistent, bioaccumulative and toxic substance, the use of mercury in many industries and products in the United States has decreased substantially over the past two decades.[3,4] Although the use of dental amalgams has also declined, the dental industry remains one of the largest consumers of mercury, and is facing regulatory scrutiny regarding the mercury content of dental wastewater.[4-6]

Since 2001, ENVIRON International Corporation has worked with the American Dental Association to develop a model of the quantity and fate of mercury in the form of amalgam introduced into dental wastewater. At the request of the California Dental Association, ENVIRON used this model to evaluate a number of issues related to the use of mercury as amalgam by the dental industry in California. Specifically, the objectives of the assessment were to evaluate: (1) the quantity of mercury used in amalgam by the California dental industry, (2) the amount of mercury from amalgam in dental wastewater that ultimately reaches surface waters in California; and (3) the cost-effectiveness of reducing these discharges through the installation and use of amalgam separators in dental facilities throughout the state.

The assessment was limited to the discharge and deposition of mercury to surface waters via the primary pathways consisting of the effluents from publicly owned treatment works (POTWs) and the emissions from sewage sludge incinerators (SSIs). It was recognized that additional pathways may exist for the discharge of mercury to surface waters, including:

- Amalgam present in biosolids managed via methods other than incineration (e.g., land application and landfilling);
- Non-contact and contact amalgam managed via methods other than recycling (e.g., in solid and infectious waste streams);
- Amalgam present during cremation; and
- Mercury in human waste which may, in part, be associated with amalgam.

For the purposes of the assessment, California was divided geographically into the northern and southern halves of the state. The geographic regions included in the definitions for both of these areas are summarized in **Table 1**.

Characteristics of the Dental Industry in California

The assessment focused on identifying and evaluating the mercury discharges to surface waters in California resulting from the use of amalgam by general dentists and specialists in private practice. According to the CDA, there are currently 25,222 such practitioners in California.[7] During the assessment, it was considered some general dentists and many specialists do not use amalgam in their practices. Although statewide surveys for California were not available, a survey recently conducted by the Sacramento Regional County Sanitation District (SRCSD) reported that approximately 72 percent of general dentists in Sacramento County use amalgam.[8] This percentage generally agreed with the results of nationwide surveys recently conducted by dental products manufacturers, which indicated that approximately 76 percent of general dentists throughout the United States reported using amalgam in 2001.[9] During the assessment, the percentage identified by the SRCSD of 72 percent was assumed for general dentists throughout California.

According to the ADA, pediatric dentists, prosthodontists, and endodontists are the only types of specialists using amalgam.[5] Due to a lack of data, it was assumed all of these specialists use

Table 2

Summary of Dentists in California and Estimates of Dentists Who Use Amalgam

Type	Northern California	Southern California	Statewide
Number of General Dentists	7,776	11,293	19,069
Using amalgam – 72%	5,600	8,100	13,700
Specialists	2,447	3,706	6,153
Using amalgam – pediatric dentists, prothodontists, and endodontists.	630	872	1,502

amalgam in their practices. The numbers of practitioners in California as provided by the CDA and the estimates of those using amalgam based on the assumptions discussed above are summarized in **Table 2**.

Estimate of Annual Amalgam Placements

Based on its 2003 survey, the SRCSD reported general dentists in Sacramento County conduct an average of eight placements per week.[8] From nationwide surveys, the ADA has estimated the average dentist in the United States works 48 weeks per year.[10] This work schedule was assumed for general dentists in Sacramento County to estimate that, on average, these dentists each perform 384 amalgam placements per year. The Central Contra Costa Sanitary District (CCCSD) conducted a similar survey in August 2000, and reported dentists within its service area perform an average of 449 amalgam placements per year.[11] Based on recent studies of dentists in areas serviced by the Union Sanitary District (USD) and the Palo Alto Regional Water Quality Control Plant (RWQCP), Barron estimated dentists in these two areas perform an average of 240 placements per year.[12,13] The amalgam placement rates identified for the SRCSD, CCCSD, USD, and Palo Alto RWQCP service areas were averaged to estimate the general dentists in these areas perform approximately 328 amalgam placements per year. This average rate was assumed for general dentists using amalgam throughout California. This rate is less than half the average rate identified by the ADA for general dentists in the U.S. of approximately 713 amalgam placements per year.[14]

None of the 23 specialists who responded to the 2003 SRCSD survey reported conducting amalgam placements, and no additional data was available regarding the use of amalgam by specialists in California. As noted, the ADA has conducted nationwide studies of the use of amalgam by specialists, and concluded that only pediatric dentists, prosthodontists, and endodontists use amalgam. According to the ADA, these specialists performed 4.7 million amalgam placements nationwide in 1999, for an average of approximately 440 amalgam placements per specialist.[14] Due to the limited data regarding the use of amalgam by specialists in California, this placement rate was assumed for the pediatric dentists, prosthodontists, and endodontists practicing in California. Considering the significantly lower amalgam placement rate identified for general dentists in California as compared to the national rate, the use of the national rate for specialists in the state was considered to be conservative. The amalgam placement estimates are summarized in **Table 3**. The estimates presented in **Table 3** and the following tables have been rounded to reflect the number of significant digits used in the underlying calculations.

Estimates of the Use and Disposition of Mercury in Amalgam

The amalgam placement rates identified above for general dentists and specialists were combined with the number of each type of dentist using amalgam in California in order to estimate the total number of amalgam placements conducted. Stone et al. reported the average mercury content per double spill of amalgam to be approximately 450 mg Hg.[15] This mass was combined with the estimated number of placements conducted in order to estimate the amount of mercury used in amalgam by the California dental industry.

Excess amalgam (i.e., "non-contact" amalgam) is commonly triturated during each amalgam placement to ensure that sufficient mixed amalgam is available to complete the restoration. The Florida Center for Solid and Hazardous Waste Management, Arenholt-Bindlsev, and Barron estimated that 15 percent to 50 percent of the amalgam triturated for placement becomes non-contact amalgam.[13,16,17] Barron's estimate of 25 percent was used as an approximate average of the percentages reported in the literature in order to estimate the mass of non-contact amalgam generated in California and the mass of amalgam actually used in placements. The calculations of the use and disposition of mercury in amalgam are summarized in **Table 4**.

When the units of the estimates presented in **Table 4** are converted to tons,

Table 3

Estimates of Annual Amalgam Placements

	Northern California	Southern California	Statewide
Number of General Dentists	5,600	8,100	13,700
Placement rate	328	328	328
Placements	1,800,000	2,700,000	4,500,000
Number of Specialists	630	872	1,502
Placement rate	440	440	440
Placements	280,000	380,000	660,000
Total Placements	2,100,000	3,100,000	5,200000

Table 4

Summary of the Annual Use and Disposition of Mercury in Amalgam

	Northern California	Southern California	Statewide
Total Placements	2,100,000	3,100,000	5,200,000
Mass Hg Per Placement	450 mg	450 mg	450 mg
Total Mass Hg Used	2,100 lbs	3,100 lbs	5,200 lbs
Hg in Non-Contact Amalgam	530 lbs	770 lbs	1,300 lbs
Hg Placed in Amalgam	1,600 lbs	2,300 lbs	3,900 lbs

it was estimated approximately 1 ton of mercury is used in amalgam in Northern California and 1.5 tons in Southern California, for a statewide total mercury use of approximately 2.5 tons. This corresponds to approximately 7 percent of the estimated 35 tons of mercury used in amalgam nationwide.[18] Approximately 15 percent of the nation's dentists practice in California, indicating that amalgam use in California may be significantly lower than the national average.

Estimate of Mercury Removed as Amalgam

The 2003 SRCSD study identified an average removal rate of about 22 amalgams per general dentist per week.[8] In 1993, researchers estimated that general dentists in the San Francisco area averaged 1.79 amalgam removals per day.[19] The aforementioned work schedule identified by the ADA (228 days and 48 weeks per year) was assumed for these general dentists to estimate that, on average, the dentists in the SRCSD and San Francisco Service areas perform 1,056 and 408 amalgam removals per year, respectively. The CCCSD, USD, and Palo Alto RWQCP studies identified amalgam removal rates of 857, 312, and 300 removals per general dentist per year, respectively.[11-13] The results of these studies were averaged to estimate that general dentists in California each remove approximately 587 amalgams per year. This average is somewhat lower than the average of the amalgam removal rates identified by the Municipality of Metropolitan Seattle; the Western Lake Superior Sanitary District in Duluth, Minn.; the Metropolitan Council Environmental Services (MCES) in St. Paul, Minn.; and the Massachusetts Water Resources Authority in Boston.[20-23] The average of the amalgam removal rates from these studies was 785 removals per dentist per year.

During its 2003 survey, the SRCSD reported that endodontists, periodontists, orthodontists, and oral surgeons in Sacramento County removed an average of 18 to 19 amalgams per week.[8] Based on the average work schedule discussed above, it was estimated these dentists conduct an average of 888 amalgam removals per year.

It was assumed that all general dentists and specialists in California remove amalgam, even if they do not regularly place amalgam in their practices. The amalgam removal rates discussed above were combined with the numbers of general dentists and specialists to estimate the total number of amalgam removals conducted in California.

The mass of mercury in an amalgam originally placed in a tooth is greater than that ultimately removed from the tooth due to losses over the life of the amalgam. Barron estimated these losses at 10 percent.[13] This estimate generally

Table 5

Summary of Annual Amalgam Removals and Mercury Removed as Amalgam

	Northern California	Southern California	Statewide
Number of General Dentists	7,776	11,293	19,069
Removal rate	587	587	587
Removals	4,600,000	6,600,000	11,200,000
Number of Specialists	1,350	1,762	3,112
Removal rate	888	888	888
Removals	1,200,000	1,600,000	2,800,000
Total Removals	5,800,000	8,200,000	14,000,000
Mass Hg Per Removal	300 mg	300 mg	300 mg
Hg Removed as Amalgam	3,800 lbs	5,400 lbs	9,200 lbs

agrees with that predicted from annual mercury loss rates reported by Skare and the United States Agency for Toxic Substances and Disease Registry and with the average amalgam life estimated by the USGS of about eight to nine years.[4,24,25] When applied to the average mass of mercury originally placed in a typical amalgam (i.e., that which is not discharged in wastewater during the placement), Barron's 10 percent estimate indicated that the average amalgam contains about 280 mg of mercury when removed from the tooth. This estimate was slightly lower than the results of a study conducted by Watson et al., which indicated an average of about 320 mg of mercury in each removed amalgam.[26] From the results of these studies, it was assumed the average removed-amalgam contains 300 mg of mercury. This mass was combined with the number of amalgam removals conducted in California to estimate the mass of mercury removed as amalgam in the state each year. The amalgam removal calculations are summarized in **Table 5**.

Estimate of Mercury in the Form of Amalgam Released to Dental Wastewater

During the Palo Alto RWQCP study, Barron estimated the fraction of amalgam particles that are released to dental wastewater during amalgam placements and removals as approximately 9 percent and 90 percent, respectively.[13] These percentages were applied to the mass of mercury placed in amalgams and removed in the form of amalgam estimated as part of this study. The calculations of the release of mercury in the form of amalgam to dental wastewater from amalgam placements and removals are summarized in **Table 6**.

Capture of Mercury in the Form of Amalgam in Dental Facilities

Dental wastewater generated from restorative procedures flows through a chairside trap and, in the majority of dental facilities, a filter that protects the vacuum pump, prior to discharge.[27] Drummond et al. identified a capture efficiency for chairside traps of 60 percent based on sampling data, while Naleway et al. estimated that chairside traps capture 75 percent of amalgam in dental wastewater based on particle size distribution studies.[28,29] An average chairside trap capture efficiency of 68 percent was selected based on the capture efficiencies reported by these studies.

No data was available regarding the percentage of dental facilities in California that are equipped with vacuum filters. Based on studies conducted in Minneapolis-St. Paul, Minn., the MCES and MDA reported that approximately 71 percent to 88 percent of the surveyed dental facilities were equipped with vacuum filters.[22,27] These estimates are similar to those reported in a study conducted by Watson et al., which estimated that approximately 90 percent to 95 percent of dental facilities in Ontario, Canada, were equipped with vacuum filters.[26] Approximately 80 percent of the dental facilities in California were estimated to be equipped with vacuum filters based on the average of the results of the MCES and MDA studies.

In 2001, the MCES and MDA conducted a detailed evaluation of the efficiency of vacuum filters in capturing amalgam particles that pass a chairside trap, and identified an overall capture efficiency of 42 percent. Particle size distribution studies conducted by Batchu et al. and Cailas et al. indicated that capture efficiencies for vacuum filters range from 25 percent to 50 percent.[30,31] An average vacuum filter capture efficiency of 40 percent was estimated based on the average of the capture efficiencies identified from these studies.

A statewide capture efficiency of mercury in the form of amalgam was calculated using the data identified in the literature for the capture of chairside traps and vacuum filters. Dental facilities equipped with both a chairside

Table 6

Summary of the Release of Mercury in the Form of Amalgam to Dental Wastewater

	Northern California	Southern California	Statewide
Placements			
Hg Placed as Amalgam	1,600 lbs	2,300 lbs	3,900 lbs
Release to Dental Wastewater	9%	9%	9%
Hg Released from Placements	140 lbs	210 lbs	350 lbs
Removals			
Hg Removed as Amalgam	3,800 lbs	5,400 lbs	9,200 lbs
Release to Dental Wastewater	90%	90%	90%
Hg Released from Removals	3,400 lbs	4,900 lbs	8,300 lbs
Total	3,500 lbs	5,100 lbs	8,600 lbs

trap and vacuum filter were estimated to capture approximately 81 percent of the amalgam particles in dental wastewater due to the combined capture of both devices, while dental facilities equipped with only a chairside trap were estimated to capture 68 percent of the amalgam particles. Based on studies conducted by the MCES and MDA, it was estimated that 80 percent of the dental facilities in California are equipped with both chairside traps and vacuum filters and 20 percent are equipped with chairside traps only.[22,27] A weighted average was utilized to estimate a capture efficiency for dental facilities in California of approximately 78 percent.

Capture of Mercury in the Form of Amalgam in POTWs

The wastewater generated by dental facilities is discharged to either POTWs or septic systems. The Maine Dental Association recently conducted a survey of its constituents, and estimated that 86 percent of the dentists in Maine discharged wastewater to POTWs and that the remainder is discharged to septic systems.[32] No data regarding this distribution in California was identified from a review of the literature. In order to provide a conservative estimate of mercury loading to POTWs in California, it was assumed that all dental facilities discharge to POTWs.

A review of the open literature was conducted to identify POTW capture efficiencies for mercury and mercury in the form of amalgam. Although substantial data was identified regarding the capture of mercury by POTWs, little data was identified for the capture of mercury in the form of amalgam. Although POTWs are not designed to capture mercury, a number of recent studies have reported mercury capture efficiencies for POTWs ranging from 95 percent to 99 percent. The most comprehensive of these studies was conducted by the Association of Metropolitan Sewerage Agencies (AMSA), and included of a review of 15 POTWs ranging in capacity from approximately 4 million gallons per day (MGD) to 375 MGD.[6] The AMSA study identified an average mercury capture efficiency for POTWs of 95 percent. Independent studies conducted by the MCES in 1995 and 1998 identified mercury capture efficiencies for three POTWs of 96 percent, 98 percent, and 99 percent, respectively.[33,34] Based on the comprehensive data reported in the AMSA study, an average POTW capture efficiency of 95 percent for mercury and mercury in the form of amalgam was used in the present assessment.

Incineration of Mercury in the Form of Amalgam with POTW Biosolids

Particles captured in POTWs are either transferred to the grit solids or biosolids. Grit solids are typically removed from the wastewater stream through the use of either horizontal-flow, aerated, or vortex grit chambers.[35] A study conducted by the MCES in 1998 identified mercury capture efficiencies for aerated and vortex grit chambers of 7 percent and 48 percent, respectively.[34] The data was compared with a theoretical capture analysis for amalgam of approximately 20 percent in a horizontal-flow grit chamber based on design specifications reported by Tchobanoglous and Burton and the amalgam particle size distribution identified in studies conducted by the International Organization for Standardization (ISO).[35,36] It was estimated that 25 percent of mercury in the form of amalgam captured by POTWs is transferred to the grit solids, and that 75 percent is transferred to the biosolids.

The California Association of Sanitation Agencies (CASA) conducted a survey of biosolids management practices in California in 1998 and reported that approximately 6.7 percent of biosolids generated were managed via incineration in sewage sludge incinerators (SSIs) at that time. The CASA study

Table 7

Summary of the Discharge of Mercury from Dental Facilities to POTWs and Surface Waters

	Northern California	Southern California	Statewide
Hg Released to Dental Wastewater	3,500 lbs	5,100 lbs	8,600 lbs
% Captured in Dental Facilities	78%	78%	78%
Hg Captured in Dental Facilities	2,700 lbs	4,000 lbs	6,700 lbs
Hg Discharged to POTWs	800 lbs	1,100 lbs	1,900 lbs
% Captured in POTWs	95%	95%	95%
Hg Discharged via POTW Effluents	40 lbs	55 lbs	95 lbs
Hg Captured in POTWs	760 lbs	1,040 lbs	1,800 lbs
% Transferred to Biosolids	75%	75%	75%
Hg Transferred to Biosolids	570 lbs	780 lbs	1,400 lbs
% Incinerated with Biosolids	5%	5%	—
Hg Incinerated with Biosolids	29 lbs	39 lbs	68 lbs
% Capture by Emissions Controls	0%	0%	0%
Hg Emitted from SSIs	29 lbs	39 lbs	68 lbs
Total Hg Discharged to Surface Waters	69 lbs	94 lbs	163 lbs

indicated that the mass of biosolids incinerated in Northern and Southern California was relatively equal. Additional information indicates that the fraction of biosolids managed via incinerations has dropped to 5 percent.[37,38] From approximately 1988 to 1995, the United States Environmental Protection Agency (EPA) developed representative emissions factors for SSIs, commonly referred to as AP-42 factors, the average of which represented a mercury capture efficiency for SSI emission controls of about 79 percent.[38] However, some of the scrubber water utilized in these control systems is recycled through the POTW. As a result, at least some of the captured mercury will be released via POTW effluents through this cycle. For the purposes of this assessment, the overall capture efficacy was assumed as 0 percent.

Estimate of the Discharge of Mercury to Surface Waters

The mercury capture efficiency of chairside traps and vacuum filters in dental facilities (78 percent) was applied to the mass of mercury in the form of amalgam released to dental wastewater during amalgam placements and removals to estimate the mass of mercury captured in dental facilities and released to POTWs in California. The POTW capture efficiency (95 percent) was then applied to the mass of mercury released to POTWs to estimate the mass of mercury entering surface waters in California via POTW effluents. The percentage of mercury in the form of amalgam transferred to biosolids (75 percent) and the biosolids incineration rate (5 percent) were used to estimate the mass of mercury from amalgam that is released from SSIs. Although some fraction of the mercury emitted from SSIs will be deposited on land and become bound to soils, all of this mercury was assumed to enter surface waters. The discharge calculations are summarized in **Table 7**.

Cost of Using Amalgam Separators to Reduce Mercury Discharges

Amalgam separators are the primary technology currently being considered to reduce the content of mercury in the form of amalgam in dental wastewater prior to discharge from dental facilities. The cost of implementing the use of amalgam separators and their effectiveness in reducing mercury discharges from dental facilities was considered as part of the assessment.

From 2000 to 2002, the ADA, the MCES and MDA, and the Palo Alto RWQCP conducted studies of the costs associated with utilizing amalgam separation equipment in dental facilities.[27,39,40] The results of these studies were reviewed and supplemented with commercial vendor quotes to estimate the cost of purchasing and operating an amalgam separator for the average dental facility in California. The separator purchase and operating costs identified during the assessment are summarized in **Table 8**.

Based on a review of the cost studies and vendor quotes, it was estimated the cost to purchase and install an amalgam separator(s) would typically range from roughly $1,000 to $2,000 per dental facility. It was estimated the cost to operate the separator(s) would typically range from $700 to $1,000 per dental facility per year.

In order to prepare a conservative estimate of the costs associated with amalgam separators, the installation and operation of separators in only those dental facilities operated by general dentists were considered. During a 1997 survey, CDA identified that approximately 73 percent of all dentists in California maintained a solo private

Table 8

Summary of Amalgam Separator Purchase and Operating Costs

Vendor	Model	Type	Purchase Price	Annual Operating Costs
AB Dental Trends, Inc.	890-1000	Sedimentation, Filtration, Ion exchange	$1,190	$476
	890-4000	Sedimentation, Filtration, Ion exchange	$1,650	$610
	890-6000	Sedimentation, Filtration, Ion exchange	$667	$441
Air Techniques, Inc.	A 1000	Sedimentation	$750	$1,150
	Durr 7800/7801	Centrifuge	$4,000	$495
Avprox, Inc.	Asdex Filter	Filtration	$215	$1,360
	BullfroHg	Sedimentation	$0	$1,200
DRNA	MRU	Sedimentation, Filtration, Ion exchange	$0	$1,800
Maximum Separation Systems, Inc.	MSS 2000	Sedimentation	$3,000	$596
Metasys	ECO II	Sedimentation	$260	$428
R&D Services	Amalgam Collector	Sedimentation	$350	$540
Rebec Environmental	RME 2000	Sedimentation	$1,895	$474
SolmeteX	Hg5	Sedimentation, Filtration, Ion exchange	$695	$496

practice.[7] Although the CDA survey did not identify the typical size of group practices in California, the ADA has reported that such practices are staffed by an average of 2.9 dentists per facility nationwide.[10] These percentages were assumed for the general dentists throughout California to estimate the number of dental facilities in the state. The calculations of the number of dental facilities and costs of using amalgam separators are presented in **Table 9**.

Effectiveness of Using Amalgam Separators to Reduce Mercury Discharges

The effectiveness of separators was evaluated as the incremental capture attained by the separator beyond that already attained by chairside traps and, where present, vacuum filters. The behavior of the amalgam fraction not captured by the separators in the receiving POTWs was also evaluated in order to determine the actual reduction in discharges to surface waters via the POTW effluent and SSI emission pathways.

The MCES and MDA recently completed a two-year study on the capture efficiency of amalgam separators in several dental facilities located in Minnesota. This study identified incremental capture efficiencies for amalgam separators of approximately 94 percent beyond the capture already achieved in facilities equipped with chairside traps and 89 percent beyond the capture achieved in facilities equipped with both chairside traps and vacuum filters.[27]

The ADA recently conducted a bench study of the amalgam capture efficiency of 12 amalgam separators in accordance with ISO Standard 11143. From the study, the ADA identified an average overall amalgam capture efficiency of 99 percent.[41] However, the amalgam sample utilized in these studies was prepared in accordance with the ISO standard, and consisted of amalgam particles ranging up to 3,150 mm in size, 60 percent of which were greater than 500 mm in diameter.[36] As noted, dental facilities are equipped with chairside traps that have pore sizes of 700 mm, and many are also equipped with vacuum filters that have pore sizes ranging from 210 mm to 400 mm. Therefore, had the ADA's tests been conducted in actual dental facilities, much of the ISO amalgam sample uti-

Table 9

Summary of the Number of Dental Facilities and Costs of Using Amalgam Separators

	Northern California	Southern California	Statewide
General Dentists	7,776	11,293	19,069
% Solo practitioners	73%	73%	73%
Number of Solo Practitioners/Facilities	5,700	8,200	13,900
Number of Practitioners Sharing Facilities	2,100	3,100	5,200
Density of Practitioners per Facility	2.9	2.9	2.9
Number of Shared Facilities	720	1,100	1,800
Total Number of Dental Facilities	6,400	9,300	15,700
Separator Capital Cost per Facility	$1,000 – $2,000	$1,000 – $2,000	$1,000 – $2,000
Total Separator Capital Cost	$6.4 – $13 million	$9.3 – $19 million	$16 – $31 million
Separator Operating Cost per Facility	$700 – $1,000	$700 – $1,000	$700 – $1,000
Total Separator Operating Cost	$4.5 – $6.4 million	$6.5 – $9.3 million	$11 – $16 million
Total Cost of Using Separators[1]	$5.1 – $7.7 million	$7.4 – $11 million	$13 – $19 million

[1]The separator capital cost was spread over an assumed separator life of 10 years and added to the annual operating and maintenance costs in order to estimate the total annual cost of using amalgam separators.

lized in the tests would have been captured by the chairside traps and vacuum filters prior to entering the amalgam separators. Upon consideration of the capture of these devices, the incremental separator capture efficiency identified by the ADA bench tests was estimated to range from 95 percent to 97 percent.

Based on the MCES and MDA study and the ADA bench tests, an average incremental capture efficiency for the use of amalgam separators of approximately 95 percent was used in the assessment. At this efficiency, amalgam separators would reduce the estimated discharge of 1,900 pounds of mercury in the form of amalgam to POTWs in California to approximately 95 pounds. The 95 pounds would consist of the smallest and most difficult amalgam particles to capture. Amalgam separators primarily employ the same physical processes to remove amalgam particles as the processes utilized at POTWs to remove particulates (i.e., sedimentation and centrifugation) and can generally be expected to remove the same types of amalgam particles. Indeed, the amalgam capture efficiencies identified for both POTWs and separators from the open literature are both approximately 95 percent. Therefore, it is unlikely a significant amount, if any, of the 95 pounds of mercury in the form of amalgam particles not captured by amalgam separators would subsequently be captured by the downstream POTWs (i.e., the 95 pounds of mercury in the form of amalgam not captured by the separators would consist of the same 95 pounds that is already estimated not to be captured by POTWs). Under this scenario, the only benefit attained through the use of separators would be the virtual elimination of the deposition to surface waters of an estimated 68 pounds of mercury from the incineration of amalgam in SSIs in California, at an estimated annual cost of reduction of approximately $190,000 to $280,000 per pound ($380 million to $560 million per ton).

A second scenario of the potential reductions in mercury discharges from the use of amalgam separators was considered for the purposes of the assessment. AMSA is currently conducting a study to evaluate whether separators have an effect on the mercury discharged in POTW effluents. From this study, AMSA has generated some preliminary data regarding average mercury concentrations in the effluent from the POTWs operated by the City of Wichita, Kan.[42] Although the data appears relatively inconclusive, AMSA has reported that the

use of amalgam separators reduced mercury effluent concentrations from the City of Wichita's POTWs by approximately 29 percent. Despite the preliminary nature of this data, a hypothetical situation was considered during the assessment in which the use of amalgam separators decreased the mercury concentrations in the effluent from POTWs in California by approximately 30 percent. Assuming this hypothetical situation, the mercury discharges from POTWs to surface waters in California would be reduced by at most 97 pounds per year, at an annual cost of reduction of approximately $130,000 to $200,000 per pound ($260 million to $400 million per ton).

Conclusions

An assessment was conducted of the use of mercury in dental amalgam in California and the discharge of mercury in the form of amalgam from dental facilities to surface waters via the effluent from POTWs and air emissions from sewage sludge incinerators. The annual use of mercury in amalgam placements in California was estimated to be approximately 2.5 tons. The annual discharge of mercury in the form of amalgam from dental facilities to POTWs as a result of amalgam placements and removals was estimated as approximately one ton. The discharge of mercury to surface waters in California via POTW effluents and SSI emissions was estimated to total approximately 165 pounds per year. A cost-effectiveness analysis determined that the annual cost to the California dental industry to reduce mercury discharges to surface waters through the use of amalgam separators would range from $130,000 to $280,000 per pound. CDA

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