Development, Evaluation and Implementation of a Testing Protocol for Evaluation of Technologies for Removal of Mercury from Dental Facilities: Part I – Field Studies and Protocol Evaluation
June 2003

Executive Summary and Recommendations

Based on the evidence gathered in this study and those conducted elsewhere, the use of amalgam separators, coupled with well-planned placement of the separator in the facility's waste disposal system and the use of effective best management practices (BMPs), would substantially reduce the release of mercury in the effluent from such facilities.

The critical variables impacting the optimal performance of the various units in this study and in others as well are most likely the conceptual design of the system (e.g. "capture and treat" vs. "in-line" treatment approach), placement of the system in the facility, and control of the pH of the effluent. The following recommendations are presented on the basis of a review of existing data and new data generated as part of an ongoing collaborative study by our laboratory at the University of Massachusetts at Boston with the assistance of a national advisory committee including the Massachusetts Dental Society and the American Dental Association, the Executive Office of Environmental Affairs and the Department of Environmental Protection and the Massachusetts Water Resources Authority. This report presents the results of an extensive field-testing of four different amalgam removal technologies in the Boston metropolitan area. Part II of this report will present the results of the development of a bench test protocol to test the efficiency of amalgam separators as an alternate to the existing ISO 11143 protocol.

We conclude that data from this study and other recent studies provide consistent evidence that the proper installation and use of amalgam separators (in conjunction with effective best management practices) can substantially reduce the release of mercury in the effluent from dental offices. Therefore, the use of such separators should be strongly encouraged. We also present a number of recommendations that would enhance and assure the proper operation of such technologies to minimize the amount of mercury released to the environment by dental treatment facilities.

Recommendation #1:

Amalgam separators installed in facilities with preexisting waste conveyance systems should be placed, if feasible, at the furthest point downstream in the amalgam wastewater discharge piping within the facility (i.e. at or near the point of release from the dental facility). Separators placed in line and releasing treated water into preexisting mercury-contaminated drainpipes and air-water separators within the facility cannot achieve optimal effluent quality and will lead to a release of mercury

that could otherwise be avoided. Cleaning of downstream pipes and air-water separators before installation is highly recommended if feasible.

Recommendation #2:

It is well known that acidic pHs will solubilize mercury, as well as most metals in the amalgam, copper pipes and other solid phases in contact with the wastewater. The use of acidic cleansers or other processing of the wastewater discharged from facilities that produce acidic pHs must be eliminated if maximum removal by amalgam separators is to be realized.

Recommendation #3:

In conjunction with recommendation #1, the treatment capacity of the technology installed should a) be appropriately sized to accommodate the volume of effluent produced, and b) be able to function effectively across the well-documented range and variability of waste water characteristics being treated. Technologies that are designed to capture, temporarily hold and then treat the wastewater using appropriate flow rate control methods are therefore most likely to produce effluents with consistently low concentrations and mass fluxes of mercury. The amalgam separator should be located so that it will not unnecessarily treat large volumes of uncontaminated water. A corollary to this recommendation is that water usage in dental facilities be minimized to facilitate the use of such capture and treat technologies.

Recommendation #4:

The ISO amalgam separator test, although providing useful information, should not be the sole basis for decisions regarding the effectiveness or acceptability of these technologies. It is recommended that the ISO test (or appropriate bench scale alternative) serve only as a base component in any certification program or other decision-making process regarding these units. Additional factors that might be considered include; the availability of field test data demonstrating effectiveness in actual clinical settings, verification of the adequacy of recommended servicing and maintenance schedules, special conditions at the dental clinic, vendor specifications regarding the sizing of the units for particular office applications (see Recommendations #3 above), adequacy of installation instructions to ensure that units are placed appropriately, and evidence that the technology will not substantially increase dissolved mercury discharges.

INTRODUCTION

Mercury is one of the most significant contaminants of both environmental and public health concern. Even minor anthropogenic introduction of mercury into the environment results in elevated mercury concentrations in critical compartments of the food chain man relies on. Exposure to elevated concentrations of mercury, often resulting in the largely bacterially mediated formation of organomercury compounds such as methylmercury, can lead to unacceptable levels of mercury in seafood rendering it unsafe for human consumption. Ecosystem level effects may also be expected but documentation of such effects is difficult. Driven primarily by human health concerns, efforts to limit the discharge of anthropogenic mercury to the environment have accelerated.

Mercury Release from Dental Facilities

Dental facilities have been reported to represent a significant source (9-76 %), of mercury to municipal sewer systems (MWRA, 2001). The control of discharges from such facilities is consequently receiving increasing attention. Arenholt-Bindslev and Larsen (1996) estimate that mercury discharges average 0.25 g mercury/dentist/day (range 0.065 to 0.84). If the clinic was equipped with an amalgam separator, mean values decreased to 0.035 g mercury per dentist per day (range 0.012 to 0.099) an average decrease of ~87%. Johnson (2000) reports discharges on the order of 0.78 g per dentist per day passing chairside traps with large variations based on reports by Drummond et al. (1995) and the Water Environment Federation (1999). Barron (2001) presents similar estimates for release from dental facilities without mercury control but practicing existing BMPs. His estimates are summarized in (Table 1). In a report released by the Metropolitan Council Environmental Services of St. Paul Minnesota and the Minnesota Dental Association (MCES/MDA) in 2001, the unweighted mean daily discharge of mercury from 6 different clinics was 0.48 ± 0.51 g/dentist/day. When weighted as a function of all days when there was clinical activity, some of which involved no activity with amalgam, a weighted mean of 0.23 ± 0.20 g/dentist/day passing both chairside traps and vacuum filters was calculated. Adjusting this value for the average 42% removal of mercury passing chairside traps captured by vacuum filters in this study produces a weighted mean of 0.40 g/dentist/day passing the chairside trap. Calais et al. (2002) report a median value of 0.50 g/chair/day in dental waste water passing chairside traps with a mean of 0.71 ± 0.66 g/chair/day. Data provided by Adegbembo et al. (2002) on the

Table 1

System	Volume Discharged (l/day)	Mercury Discharged (g/day)	Mercury Concentration (mg/l)
Wet Cuspidor	1136	0.34	0.30
Dry Vacuum	3.8	0.40	106
Wet Vacuum	458	0.40	0.87

Source: Thomas Barron, Presentation to the Bay Area P2 Group, February 14, 2001.

average mass of amalgam released per procedure, based on the analysis of release from 190 procedures, can be used to calculate a mean of 0.44 g amalgam/procedure that passes a chairside trap. Assuming a 50% Hg content, and an average of two procedures/day/dentist involving the use of mercury amalgam, the release of Hg/dentist/day is 0.44 g.

More recently, Barron (2002) estimates releases of about 0.1 g/dentist/day, substantially lower than his previous estimate. The lower estimate of mercury release/dentist/day by Barron (2002) is primarily the result of a five-fold reduction in the estimated number of procedures involving amalgam removal (from 5 to 1/dentist/day). Dental activity in this work, which is an underestimate due to failure to document all procedures, was 1.6 ± 0.6 procedures involving amalgam restorations only per day. A similar mean of 1.6 ± 0.7 amalgam restorations was recorded by the Metropolitan Council Environmental Services of St. Paul Minnesota and the Minnesota Dental Association (2001) during their extensive testing while a mean of 4.2 restorations/day/dentist (95% confidence interval 3.8 – 4.8) was recorded in a 1990 survey of 93 general practitioners in a study conducted in Seattle (Munincipality of Metropolitan Seattle, 1991). Cameron et al. (1998) report a range between 4.2 and 4.6 restorations/dentist/day based on data from Minneapolis/St. Paul, Seattle, Boston, and from a national survey by Martin et al. (1995). They report a value of 2.2 for San Francisco. If in fact the average in most areas is closer to 4 restorations/dentists/day, then the revised estimate of Barron above would be similar to the release estimated earlier of ~ 0.4 g/dentist/day.

Much lower estimates are reported using data generated using EPA Methods 245 or 1631 for wastewater analysis. Unless validated using suitable references standards, it is unlikely this method will provide quantitative estimates of the mercury in wastewater containing significant quantities of the larger amalgam particles commonly found in dental waste streams. Preliminary work in our laboratory suggests that the 245 method releases most of the mercury from small quantities the fine particle solids in suspension trapped in the amalgam separators, very little of the mercury is released from mm sized amalgam scrap. Estimates of mercury contributions from dental facilities using EPA Method 245 or 1631 such as those reported for the Boston metropolitan area (MWRA, 1997) and by the Association of Metropolitan Sewerage Agencies (AMSA) using a loading of 0.056 g/dentist/day (Larry Walker Associates, 2002) may therefore be underestimates of the actual release from dental facilities. Our estimate of mercury loading in this report is based only on data using rigorous digestion procedures such as that used in the analyses reported in this work. We believe a more accurate estimate of the loading from such facilities, based on the data referred to above, is ~0.4 g/dentist/day, a factor of ~7 higher. Consequently dental facilities discharging to municipal sewer systems are probably much larger sources than that estimated in these and other reports using EPA Methods 245 and 1631 as the analytical method of choice to generate effluent mercury concentrations.

It can also be argued that a large fraction of the larger amalgam particle associated mercury not detected by EPA Methods 245 and 1631 is trapped in the sewer pipes and never reaches the treatment facility, at least as large particles. However, slow dissolution and/or "weathering" producing smaller, more transportable particles, could be expected to result in a persistent detectable increase in influent mercury concentrations. The lack of information on environmental mobilization of mercury from amalgam particles has been noted by McGroddy and Chapman (1997) and inhibits informed decision-making regarding the fate of amalgam mercury released to the environment. Release of mercury from amalgam particles has been shown, however, to result in elevated mercury concentrations in fish exposed to water containing amalgam particles (Ekroth, 1976; Kennedy, 2003).

Importance of Best Management Practices

Barron (2001) estimates that a significant fraction of the amalgam used by dentists can be removed without the use of amalgam separators by the use of BMPs such as the use of screens and filters (chairside traps and/or vacuum filters and proper disposal of amalgam scrap material). Using a chairside removal efficiency of 60%, and a vacuum filter or screen removal efficiency of 50%, he estimated that about 80% of Hg could be removed from the waste effluent. However actual removal by chairside traps measured by Adegbembo et al. (2002) was only about 32%, much lower than the removal efficiency of 60% used in the estimates by Barron (2001). Furthermore, in a recent study conducted in Minnesota dental facilities, vacuum filters, if present in the system, captured 16 - 80% of mercury passing through chairside traps (MCES/MDA, 2001). Removal by chairside traps was not evaluated. Using the chairside removal efficiency of 32% observed by Adegbembo (2002) and the vacuum filter removal efficiencies of 16 – 45 % observed in the Minnesota work (excluding the one vacuum filter removal of 80% observed for a low effluent concentration), it is possible to estimate a net removal of between 43 and 63 %. The remaining 67 – 37% (or more in the absence of a vacuum filter) would be discharged from the facility in the absence of use of other control devices such as amalgam separators (see below).

It is important to recognize these data refer only to mercury discharges passing chairside traps and excludes other waste sources of mercury (disposal of excess amalgam, tool cleaning, or improper disposal of material trapped in the chairside trap and vacuum filter), normally captured by the use of rudimentary best management practices. It is therefore important to note that much of the data reported and discussed in this report is predicated on the assumed use of appropriate BMPs. BMPs remain a critical component in the management of dental mercury wastes and are considered a necessary critical component complimenting the use of amalgam separators. If BMP filters and screens are used and managed inappropriately (e.g. if amalgam wastes captured are thrown in the trash, red-bagged or washed down another drain, which have been the practice at some dental offices), substantial mercury inputs to wastewater and/or solid waste will continue to occur even with the use of amalgam separators.

Variability in Waste Stream Loadings

It is also well established that the composition of wastewater discharged from dental facilities are quite variable on a time scale of days and perhaps even hours although to our knowledge this latter assumption has not been evaluated. It does seem logical however that the discharge would reflect the activity in the facility that does indeed vary on a time scale of minutes. This known variability will be an important element in the analysis and interpretation of data produced by this work.

Amalgam Separators

The use of amalgam separators referred to above has been implemented to reduce these discharges. Mercury amalgam separators consist of a variety of technologies using filtration, centrifugation or settling, sometimes in concert with applications to remove dissolved mercury as well particulate mercury from dental facility waste streams. As noted above the use of these devices can potentially reduce the discharge from dental facilities by about an order of magnitude. Mercury discharges, even with the reductions reported by Arenholt-Bindslev and Larsen (1996) and MCES/MDA (2001) for facilities with amalgam separators, still represent annual discharges of ~0.2 to 20 g mercury per dentist per year to either public sewer systems or private septic systems. It should also be noted that the sludge from the latter are ultimately treated in publicly owned sewage treatment facilities as well. The ability of commercially available separators to produce consistent high quality (low mercury concentration) effluents has not been well documented and there has been some resistance to adopt their use for that reason. The results of this project will add to the growing body of information on actual assessment of their actual in-field capability to reduce mercury concentrations in wastewater produced in dental facilities.

APPROACH

There were two major goals of this project. The first was to evaluate current methodologies used to assess the performance of amalgam separation technologies. The second was to extend the field observations of performance previously made by the MWRA in their evaluation of four different technologies being utilized in the Boston metropolitan region. These goals and the approach used to achieve them are detailed below. We approached the goals of the project in two phases. In the first phase, we assessed existing protocols. Based on our review, we recommended to a technical advisory committee that an alternative approach to the ISO protocol would provide cost-effective, scientifically credible information. The development of this alternative protocol is described in Part II of this report.

ASSESSMENT AND SUGGESTED REVISION OF EXISTING PROTOCOLS

As noted above, there are numerous technological approaches to accomplish amalgam removal and a number of protocols used to test these technologies have or are being developed to assess their effectiveness. Below we:

1. review existing testing protocols,

2. suggest revisions to such protocols,
3. where appropriate, assess performance criteria required to maximize mercury discharge control, and
4. evaluate performance of a number of these systems using either existing or revised protocols.

Review of Existing Testing Protocols

There are a number of technologies commercially available for the point-of-use control of mercury releases from dental facilities (see, for example, Fan et al., 2002). Until recently, standardized protocols whereby potential regulators or users of technologies to control mercury emissions from dental facilities could verify their performance have been unavailable. Access to uniform testing protocols to make such an assessment has inhibited implementation of the use of the technologies.

There are currently two major testing protocols in place. The ISO protocol, "Dental Equipment-Amalgam Separators", was developed in late 1999 by the International Organization for Standardization (ISO, 1999, http://www.iso.ch/iso/en/ISOOnline.openerpage). A second protocol, referred to below as the NSF/EPA Protocol, has recently been published by NSF International and was developed under EPA's Environmental Technology Verification (ETV) Program (http://www.epa.gov/etv/pdfs/vp/04_vp_mercury.pdf.). A third testing protocol was used in a cooperative effort of the Minnesota Dental Association and St. Paul Metropolitan Council Environmental Services (MCES/MDA, 2001)) to assess the performance of a number of mercury control technologies in actual clinical settings (hereinafter designated as the MCES/MDA Protocol). Their efforts evaluated both solid and aqueous phase mercury in the effluent after treatment by the various technologies. Another testing protocol was developed by King County, Seattle but its use has been discontinued. Another protocol is being developed in Canada but was unavailable at the time of this review.

These protocols are distinctly different in their approach. Each is briefly reviewed below and their advantages and disadvantages discussed with respect to their ability to ground-truth the various available technologies used for mercury amalgam control.

ISO Protocol

The ISO testing protocol focuses on a standardized method to estimate, using a controlled bench scale assessment, the reduction of the mass of mercury amalgam passing through amalgam separators. The standardized protocol is rather straightforward and measures solids removal efficiencies of the technologies as the assessment of performance. Unfortunately, it does not assess removal of mercury directly and as such cannot be used to evaluate technologies where mercury removal to low levels is required.

The basic principle of this protocol is to provide a standardized method to measure, gravimetrically (e.g. by amalgam particulate mass), the ability of the technology being tested to remove solid material with the density and characteristics of dental amalgam from the waste stream of dental facilities. Briefly, the protocol involves challenge of the technology used to control amalgam release with a standardized amalgam solids mixture and assessment of the fraction of the mass of solids retained that are above the size of 1.2 μm. From a mercury release perspective, a 95% amalgam removal (5% amalgam release) would imply a release of 0.025 g of mercury/g amalgam processed. If the average release of mercury/dentist/day is ~ 0.4 g (see above) without amalgam separators, a 95% capture would produce a release of 0.02 g/dentist/day similar to that observed by Arenholt-Bindslev and Larsen (1996, 0.035 g/dentist/day) in wastewater discharged from dental clinics using amalgam separators. At 99% efficiency, mercury release would be ~ 0.005 g/dentist/day, considerably lower than that observed by Arenholt-Bindslev and Larsen (1996).

Amalgam separators are primarily used to treat mercury in waste streams passing interceptors such as chairside traps that generally retain particles > 0.7 mm and vacuum filters that retain particles as small as 0.42 mm in diameter. However, the mix of size fractions used in the ISO protocol is designed to mimic that in dental wastewater *in Toto* where 60 % of the amalgam mass used to challenge the amalgam separators is in a size range of 0.5 to 3.15 mm. Prediction of amalgam separator efficiencies using the current ISO standard may thus be expected to overestimate that actually realized in field use. A more accurate assessment of amalgam separator efficiency would ideally be based on a more realistic amalgam solids mixture than that used in the ISO testing protocol. Use of the amalgam fractions 2 and 3 alone (particle sizes ≤ 0.5 – 0.1mm and ≤ 100 μm respectively) described in the ISO protocol, rather than the combination of the three size fractions, may therefore provide a more realistic assessment of amalgam solids removal in dental facilities using BMPs.

NSF/EPA Protocol

The NSF/EPA protocol (NSF, 2001) focuses on mercury removal as the specific testing criteria and therefore permits a more direct testing of the technology's abilities to reduce mercury in dental office waste streams. A general description EPA's Environmental Technology Verification (ETV) Program is provided and a general outline of the testing process presented in Figure 1. The end product of the test is the issuance of a verification report and a verification statement, the latter of which is a document that summarizes the experimental design and test results that are presented in more detail in the Verification Report. Both NSF and EPA representatives sign the Verification Statement. The protocol is designed to verify vendor's claim of performance in the removal of amalgam and mercury and to evaluate several other technology related issues.

It is a site-specific testing protocol; all testing for verification purposes is conducted at an actual dental clinic producing amalgam and mercury waste streams as part of its routine operation. Suitable sites are those removing or placing at least 40 amalgam surfaces per week. A minimum five-week sampling period with collection of a minimum of 25 samples of the influent to be treated is required as part of the characterization phase of the verification. The characterization phase must be completed before the testing phase of the verification process begins and use of the technology occurs. Influent samples are separated into settleable solid and aqueous phases

Figure 1: Verification Testing Process

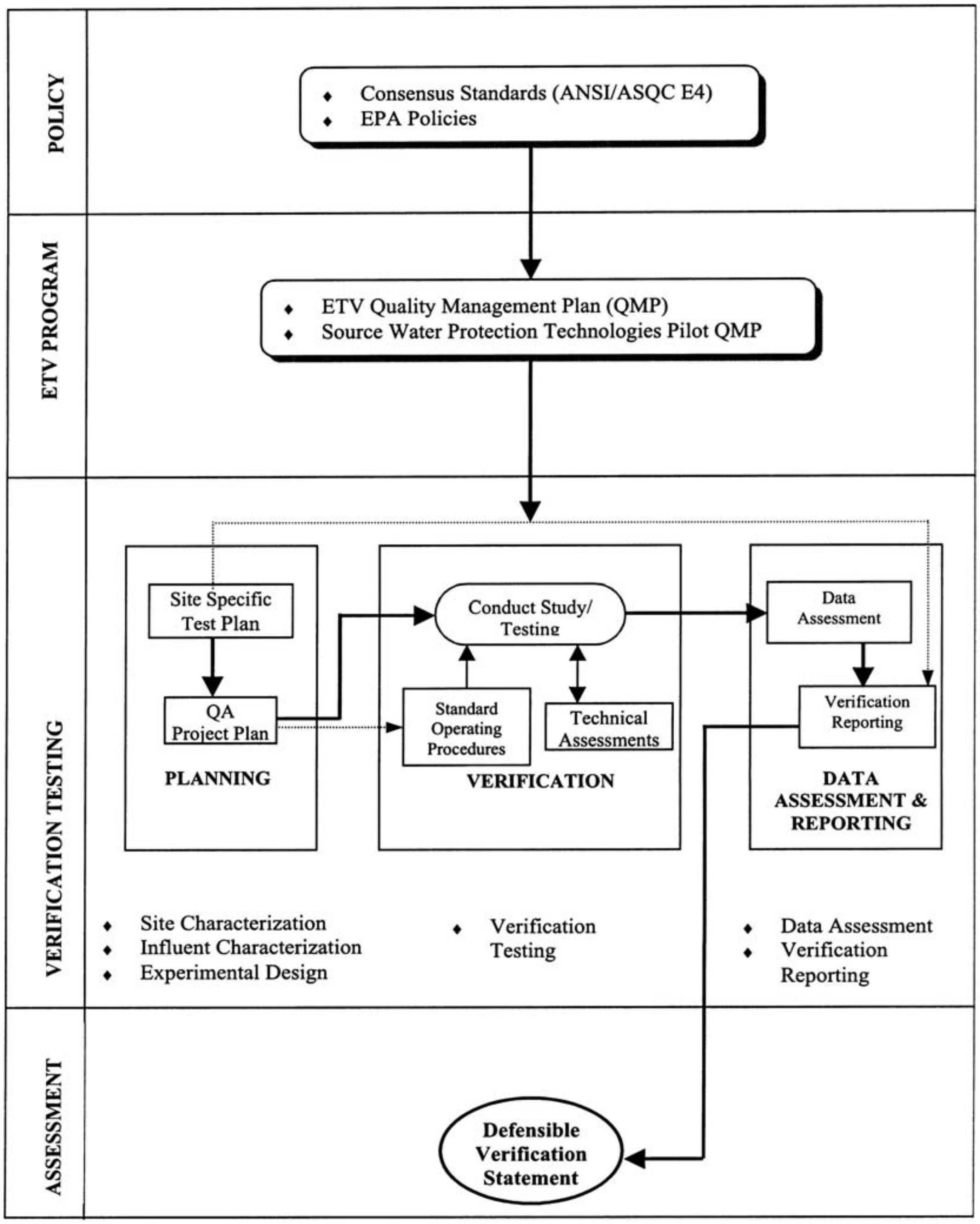

Figure 1. Source: Figure 1 in NSF (2001), used with permission.

operationally defined by gravitational settling over an 8 – 16 hour period. EPA or Standard Methods must be used to analyze the fractions. Analytical parameters for influent characterization are given in Table 2.

Table 2

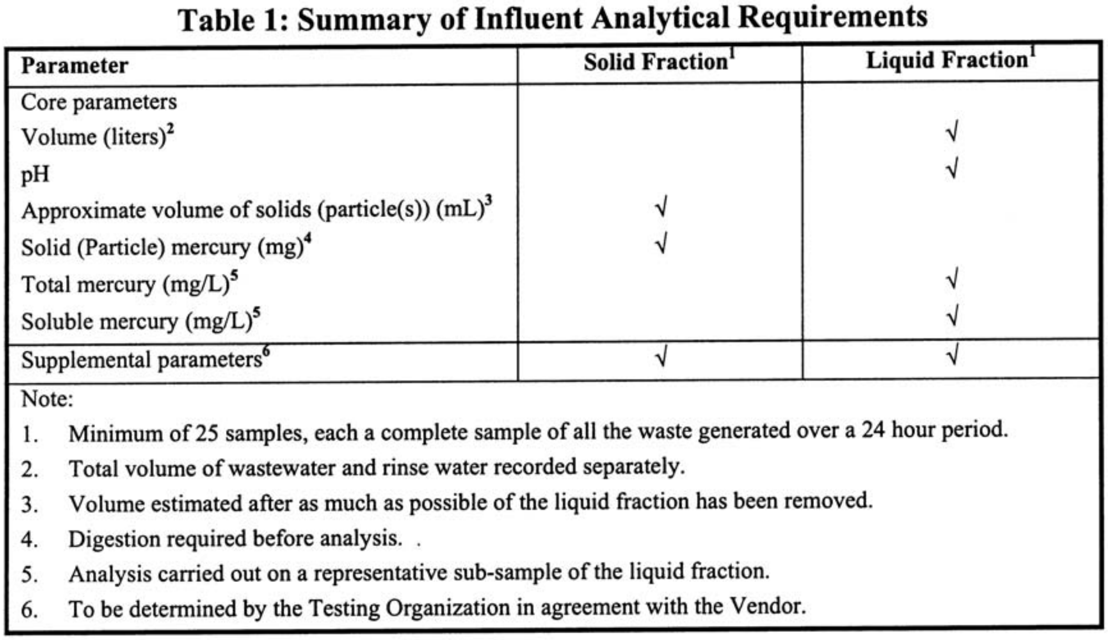

Table 1: Summary of Influent Analytical Requirements

Parameter	Solid Fraction[1]	Liquid Fraction[1]
Core parameters		
Volume (liters)[2]		√
pH		√
Approximate volume of solids (particle(s)) (mL)[3]	√	
Solid (Particle) mercury (mg)[4]	√	
Total mercury (mg/L)[5]		√
Soluble mercury (mg/L)[5]		√
Supplemental parameters[6]	√	√

Note:

1. Minimum of 25 samples, each a complete sample of all the waste generated over a 24 hour period.
2. Total volume of wastewater and rinse water recorded separately.
3. Volume estimated after as much as possible of the liquid fraction has been removed.
4. Digestion required before analysis. .
5. Analysis carried out on a representative sub-sample of the liquid fraction.
6. To be determined by the Testing Organization in agreement with the Vendor.

Source: Table 1 in NSF (2001), used with permission.

Following installation of the technology to be verified, a test period with sampling requirements identical to those of the influent sampling is required, with samples of treated effluent being collected. Sampling of residuals (material retained by the technology) as well as effluent sampling is required to characterize removal efficiencies. Influent concentrations are not monitored in this phase of the protocol. Residual sampling is required once a week or at the end of the test period depending on the technology being used. Analytical parameters for effluent and residual characterization are given in Table 3.

The influent, effluent and residual sampling and analytical regime must accommodate all parameters claimed by the vendor to be removed/controlled by the given technology. An assessment of the toxicity characteristic leaching potential (TCLP, USEPA Method SW 846 1311) on the residual solid phase is required (Table 3). Extensive quality assurance quality control requirements are given as well as equally extensive data management, analysis and presentation requirements. Overall the protocol is well documented and requires the use of EPA, APHA, AWWA and WEF Standard Methods and protocols. However the specific analytical methods to be used are not specified although such guidance might be useful. For example it might be assumed that EPA Method 1631E, http://www.epa.gov/ost/methods/1631.html, could be used in the collection, preservation, and analysis of the wastewater samples. However this would be a poor choice except in effluents with very low mercury concentration in that this method is designated for use with samples < 100 ng Hg/L and with low, easily oxidized, suspended matter contents. It would therefore not be suitable for effluents with high relatively resistant particulate matter characteristic of dental wastewater effluents.

Table 3

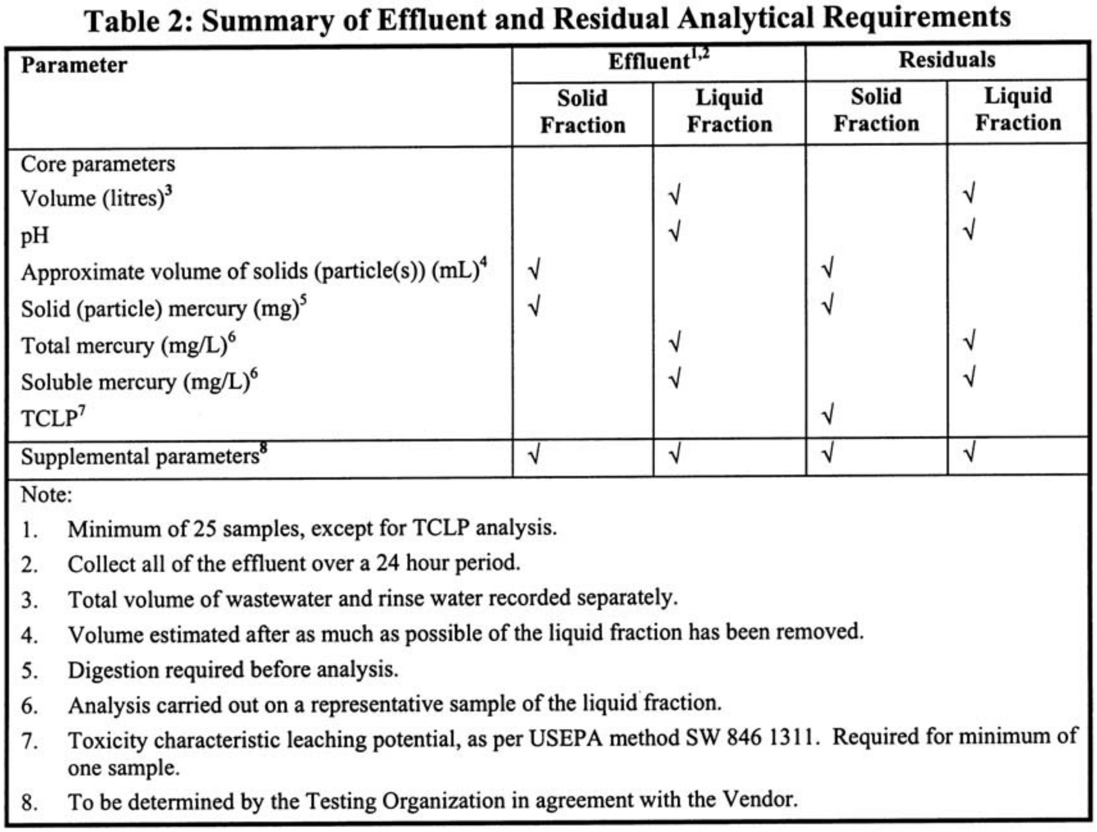

Table 2: Summary of Effluent and Residual Analytical Requirements

Parameter	Effluent[1,2]		Residuals	
	Solid Fraction	Liquid Fraction	Solid Fraction	Liquid Fraction
Core parameters				
Volume (litres)[3]		√		√
pH		√		√
Approximate volume of solids (particle(s)) (mL)[4]	√		√	
Solid (particle) mercury (mg)[5]	√		√	
Total mercury (mg/L)[6]		√		√
Soluble mercury (mg/L)[6]		√		√
TCLP[7]			√	
Supplemental parameters[8]	√	√	√	√

Note:

1. Minimum of 25 samples, except for TCLP analysis.
2. Collect all of the effluent over a 24 hour period.
3. Total volume of wastewater and rinse water recorded separately.
4. Volume estimated after as much as possible of the liquid fraction has been removed.
5. Digestion required before analysis.
6. Analysis carried out on a representative sample of the liquid fraction.
7. Toxicity characteristic leaching potential, as per USEPA method SW 846 1311. Required for minimum of one sample.
8. To be determined by the Testing Organization in agreement with the Vendor.

Source: Table 2 in NSF (2001), used with permission.

A residual analysis is required to provide an estimate of the total mass of mercury discharged over the time period assessed and a time-averaged estimate of overall efficiency of removal. More importantly the variability and mean concentration and flux of mercury in the effluent is determined. Unfortunately the mismatch in sampling resolution of effluent (daily) and residual fractions (weekly or once at the end of the testing period) precludes accurate evaluation of potential causes in the temporal variability in efficiency of removal that probably reflects responses caused by variable influent concentrations and composition. If efficiencies are of primary interest, the relationship of these efficiencies to actual effluent concentration variations should be established by simultaneous monitoring of both influent and effluent concentrations rather than on comparisons of residual and effluent fractions. Overall efficiencies of a given device as defined in this protocol may not successfully predict effluent concentrations and flux based on actual use in other facilities where the patterns in variability may not be the same as the facility used in the validation protocol.

The NSF/EPA protocol provides independent verification of overall performance of the technology being tested but is likely to be expensive, time consuming and places emphasis on efficiency of performance rather than absolute mercury control criteria. In addition, the technology is tested at a single site. The degree to which a single site-specific test provides representative data that can be extrapolated to other facilities with potentially different wastewater characteristics has not been evaluated. A more effective screening of amalgam separators would be assessment of removal efficiencies and effluent mercury concentrations and fluxes at a statistically valid number of different installations. Given the expense of the NSF/EPA protocol, an alternative approach might be to assess effluent concentrations and composition at a number of different sites rather than focus on the determination of efficiency. It raises the fundamental question on whether testing protocols should be assessing performance on removal efficiencies or the assessment of the technology to maintain mercury concentrations in the effluent, regardless of the well known variability of influent composition, at acceptable levels.

MCES/MDA Protocol

The MCES/MDA (2001) protocol used in their assessment of five technologies is quite similar to the NSF/EPA protocol described above. It focuses on measurement of the mass of mercury passing through the technologies being tested in actual use in active dental facilities. Baseline sampling was conducted prior to installation of the technologies for comparison in some clinics. Whole effluent wastestreams were collected in most cases, and were separated into solids and aqueous phase fractions by simple gravitational settling. Aqueous phase samples therefore contain fine particle, colloidal and dissolved forms of mercury. All of the solids samples were digested and the solubilized fraction analyzed after removal of the undigested solids by filtration. EPA Method 245.1 was used for the aqueous phase mercury analysis while the solids digestion followed the procedures of Method 3030 E, Standard Methods, 18th Ed., 1992. Recovery of mercury from digestion of amalgam of known composition was 89 ± 16%. The results of this testing program have been recently published (MCES/MDA, 2001).

Unlike the ISO Protocol, but similar to the NSF/EPA protocol, this approach provides actual discharge values of mercury in solid and aqueous forms during actual use that can be directly compared to desired outcomes (criteria). Comparison of the post installation effluent concentrations with those derived from baseline measurements provide a reasonable assessment of the overall solids and aqueous phase reductions in mercury release achieved by these devices. No laboratory testing of the devices was conducted prior to their use for comparative purposes. The goal was to gain experience with the devices operating in clinics, to quantify baseline loadings, and evaluation of the reduction in clinic discharges of mercury using amalgam separators. They believed that *in situ* testing would provide a more realistic assessment of the technologies abilities to process actual waste streams with their potentially inherent temporal heterogeneous composition and concentration as well as their application in different physical system types (dry vs. wet vacuum waste systems). The disadvantage of this approach, as is the case for the NSF/EPA protocol, is the expense of the testing itself. As in the NSF/EPA protocol there is no requirement for replication of the testing of individual technologies at more than a single site although four of the technologies were in fact tested in more than one clinic.

DEVELOPMENT AND IMPLEMENTATION OF AN AMALGAM REMOVAL BENCH TEST PROTOCOL

The proposed bench test protocol has been developed within a framework that recognizes the following principles:

- The bench test protocol should accurately reflect the probability of a given technology to reduce amalgam in dental waste streams
    - The protocol is expected to provide indications of the levels achieved based on comparison between performance assessed using the protocol and actual in-field observations of performance. The protocol is not designed to evaluate technologies with enhanced dissolved mercury removal capabilities (see below). Accurate assessment of the full capabilities and potentially superior performance of such advanced units requires actual in-field assessment trials. The bench test component of the protocol developed here should provide a minimum estimate of mercury removal.
    - The protocol should provide a reasonable certainty with respect to performance in removing amalgam to a threshold established by comparison of bench test with actual in-field use evaluation. Comparison of the bench-testing component of the protocol with field evaluations performed as part of this contract, as well as critically reviewed data derived from field tests conducted elsewhere using the same units, will be used in this comparison.
- The primary assessment criteria used to evaluate mercury amalgam removal technologies is the reduction in mercury concentration and flux in the waste stream and not efficiency of removal.
- The bench test protocol must be simple in design, reliable, rapid and inexpensive. The protocol will be well-defined and easy to replicate in a wide variety of settings with minimal operator skill required.

Rationale for Proposed Bench Test Protocol

Because the data provided in the use of other than the ISO protocol is not readily available or limited in scope, this discussion is necessarily quite limited and subject to revision. The relative simplicity and moderate expense of the ISO protocol is its chief advantage. The availability of data to compare the efficacy of mercury control with ISO

Protocol results on individual technologies would greatly enhance the use of this protocol. Such a database to our knowledge is not yet available. Fan et al. (2002) recently presented the results of ISO 11143 testing of a number of separators in which total and dissolved (0.45 µm filtrate) mercury in the effluent was also measured. There was no significant difference in efficiency of removal between empty and full ISO testing result for each of the units. There were large ranges in the total and dissolved mercury concentrations reported for each unit. We regressed the low and high total Hg concentrations in Fan et al.'s (2002) data against efficiency to see if lower concentrations were observed at higher efficiencies. Using either the low or high concentrations produced highly significant linear regressions ($p<0.001$) (Figure 2).

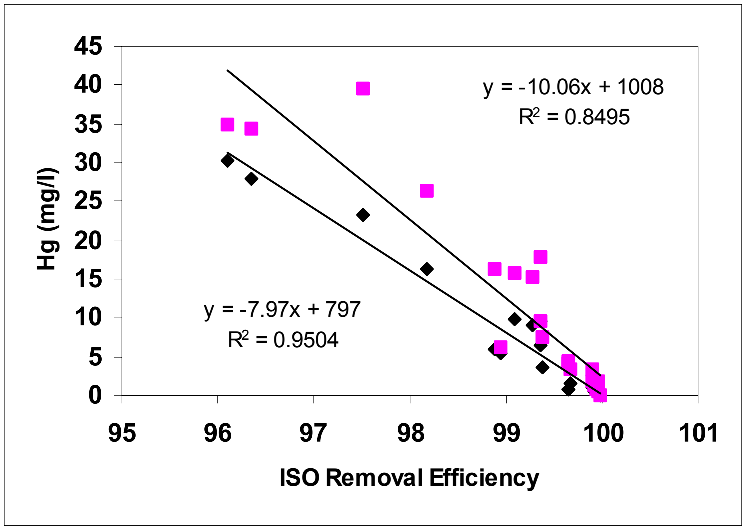

Fig. 2. Mercury concentrations in effluent as a function of ISO measured removal efficiency.

The intercepts of both slopes approach 0 as efficiencies of 100 % are approached and indicate a decrease in concentration of about 8-10 mg/l for each 1% increase in efficiency. These slope values are of course unique to the experimental conditions employed (e.g. use of pure amalgam particles and at flow rates and pHs that may not reflect actual wastewater conditions) and are probably higher than would be observed as a function of actual wastewater concentrations. Until changes in actual effluent quality are compared with ISO or other measures of efficiency, we can only infer that use of the technologies passing this test in dental clinics is likely to provide mercury control to the extent of ~ 0.04 g mercury/dentist/day, about an order of magnitude less than that achieved in dental facilities where BMPs alone are employed.

The necessary data for linking ISO type performance data to mercury in effluents could be obtained by using a modification of the NSF/EPA protocol on devices previously lab-tested using the ISO Protocol or, preferably, modified to focus on removal of the fine particle sizes rather than the existing solids mix used in the current ISO protocol (see earlier discussion). If more stringent mercury control (i.e., ≤ 0.04 g mercury per dentist per day) is the desired endpoint, then implementation of an NSF/EPA or MCES/MDA type protocol in site-specific settings would be required and is likely to be costly and time intensive.

Alternatively, simple laboratory-based tests of technologies using the ISO Protocol combined with field assessment of mercury in the effluent of the same technology being tested in the laboratory might be useful in providing a more cost-effective assessment protocol. While comparison of the simplified bench-testing protocol with assessment of actual mercury concentrations and fluxes observed in multiple field sites (beyond those correlations performed in this study and critically reviewed available data) as discussed earlier may lead to a more consistent and robust linkage between bench test and actual field performance, such an undertaking was beyond the scope of this project. However if sufficient data on the technologies tested in this work become available as a result of other NSF/EPA or MCES/MDA type protocols, such a comparison may be possible.

With the discussion of the various protocols above as a background we are proposing the following protocol to meet the principles initially stated that can be achieved with minimal expense and skill required after initial “calibration” using *in situ* generated data. Because the protocol also avoids the use of amalgam, it contributes to the growing green chemistry efforts to reduce the use of potentially toxic substances in laboratory procedures. The central hypothesis in this research is that the bench-test protocol will provide a predictive tool, within a broad categorization framework, to evaluate mercury amalgam removal technologies.

The protocol is composed of two parts, a simple rapid bench-test protocol, and linkage of those results to data on effluent mercury concentrations from the same units in the field gathered using a field protocol. The field protocol also includes a methodology to evaluate data from other existing sources. Where the data generated passes critical review, the information will be used to supplement observations made in this work. The goal is to develop, or at least set the framework within which to develop, a sufficiently robust database linking bench-test protocol results to mercury effluent quality (mercury flux in effluent). Linkage of the proposed bench test protocol to actual field assessment of the technologies should support development of a predictive capability for the testing of new units ideally based on the bench-test protocols only. This information will be provided in Part II of this project.

The predictive capability of the bench-test protocol as implemented in this project is not intended to provide highly precise estimates of mercury concentrations and fluxes in the effluents from various technologies. It is however, designed to provide rough estimates of effluent quality to assure performance within several broad categories. Based on preliminary investigations we hope to be able to eventually categorize the units as achieving mercury effluent mass fluxes in the ranges of >100 mg/day range, 10-100 mg/day, 1-10 mg/day, and <1 mg/day. The field data should provide data on the quantities and fluxes of mercury observed for each technology. We assumed that the units installed in the various field locations have been properly sized to process the composition and volume of the waste stream at each site. Normalization to dentist activity is done for comparative purposes as this has been frequently used as a benchmark in the literature.

BENCH-TEST PROTOCOL

This protocol follows the procedure described in the ISO Protocol with the following exceptions. The precise nature of the equipment used will be altered to use comparable, but readily available, off-the-shelf laboratory equipment to conduct the tests. The test slurry will be prepared using size separated quartz (sand). Size separation of the sand is accomplished using a nested set of certified sieves in a ROTO-TAP to separate three fractions similar to those used in the ISO test; 0.5-3.15mm, 0.1-0.5mm, and ≤0.1mm. Size distribution of the ≤ 0.1 mm fraction is determined using standard grain size analysis techniques. The sized fractions will be combined and used to challenge the amalgam separators as described in the ISO Protocol. In addition, a second challenge series is conducted in triplicate using just the two smaller size range fractions in the same proportion as in the original challenge material. Finally we conduct a third series of tests in triplicate using only the finest size fraction. We hypothesize that the finer size fractions, in combination with the lower density sand particles, provide a broader and thus more sensitive range in performance using the bench-test protocol proposed here than that provided by the ISO amalgam bench test. The anticipated broader range in performance data facilitates comparison to the ranges of performance observed in actual field performance data.

Note that the objective using this approach is to acquire a relative measure of the different technology’s performance that can be related, in turn, to relative differences in mass fluxes of mercury observed in the field. By using the lower density sand relative to amalgam we expected there to be larger differences in the results of the bench-tests reflecting differences in capabilities to remove settleable particles, especially in the smaller size fractions. Performance data from all three test series are compared to effluent concentrations produced by the same units operating in the field (see Field Protocol below). Comparison of performance measured in the field (effluent concentrations) with results of each of the three tests will be used to ascertain which of the three bench tests results is a better predictor of performance. The final bench test protocol will be based on these results.

FIELD PROTOCOL

The results of the bench tests are compared to effluent concentrations measured in four different amalgam separation technologies installed in four different dental facilities located in the Boston Metropolitan area. We attempted to solicit the collection of samples at additional locations where other amalgam separation units were installed to achieve a broader range of technology types and application settings. Unfortunately despite efforts to do so, we were unable to gain access to any other facilities other than the four facilities referred to above. We are attempting to identify and evaluate data on effluent quality obtained in other independent testing for as many different technologies as possible for inclusion into the data set.

Sample Collection

Initial attempts were made to collect waste samples using trace-metal-clean polyethylene or glass sampling containers of a number and size to accommodate a week's volume at each of the test facilities. Our intent was to collect the full volume discharged over a one-week period using 20 L carboys. However the flow at three of the four facilities was larger than anticipated and required the use of automated ISCO samplers equipped with acid-cleaned silicone tubing and glass jars to collect weekly composite samples. The samplers were programmed to collect 500 ± 10, 336 ± 4, and 169 ± 2 mls every 5 minutes at sites B through D respectively. The entire wastewater discharge at site A was captured. Connections and placement of the tubing and sampling apparatus were located immediately downstream of the amalgam separator in a manner to eliminate any residual settling of solids in the tubing leading to the sampling container.

The placement of the sampling device in this manner was however not possible at one of the sites (Site A). The separator at this site was placed in the plumbing system in such a way as to prohibit sampling immediately after the separator. For this reason data acquired from this site was not indicative of the performance of the separator but largely reflected release of mercury from the plumbing and air water separator located between the unit and the only accessible sampling point (see below). At two of the facilities we also collected daily samples in an attempt to capture the entire flow that allowed estimates of the flux for those sampling periods. For logistic reasons we were unable to perform daily sampling for the majority of the sampling effort over a ten week period. At the end of the sampling period, sample containers were sealed at the facility and transported to UMass for processing and analysis. Total weights of the samples collected each week were recorded and the pH of each sample was determined on a small aliquot of each sample in the field and before processing. There was no significant difference between the two readings.

Information on the number and types of activities in the dental facilities contributing to the waste stream was collected. Each dentist was asked to record the number and types of processes conducted on a daily basis and also indicate whether the removal or placement could be categorized as small, medium and large. The level of participation varied somewhat but we believe the majority of the procedures conducted were recorded. Because of the underreporting, however, the number of procedures involving mercury amalgam reported in Tables 1-4 in Appendix A are probably an underestimate.

Sample Processing

Samples were not preserved by acidification in the field to minimize post-sampling exchange between “particulate” and “dissolved” phases (operationally defined by filtration using 0.4 µm polycarbonate membrane filters). Three operationally defined fractions of mercury in the waste water samples were analyzed, a settleable solid phase defined as the fraction settling out of the sample by gravity overnight, a suspended phase consisting of slowly settling particles in the supernatant after settling and retained on a 0.4 µm polycarbonate membrane filter, and a dissolved phase that passed the 0.4 µm filter that contained colloidal and truly dissolved mercury.

We used the following procedure to fractionate the samples into it three components. Samples were allowed to settle overnight after being returned to the laboratory. The settled solids are removed by suction using a small peristaltic pump and rigid plastic tubing. The solids recovered in this fashion are transferred into 250 ml Teflon separatory funnels and allowed to settle for at least an additional hour. The settled solids in the separatory funnel were then transferred to an appropriate sized preweighed polycarbonate centrifuge tube by opening the stopcock at the base of the funnel. The separatory funnel containing the supernatant remaining after withdrawal of the settled solids is shaken and the contents returned to the original sample container.

The centrifuge tube containing the settled solids was centrifuged at 2000g for 10 minutes to further separate the solids from the sample. The liquid phase was decanted and added to the supernatant isolated earlier. The original sample container, containing the original sample less the settled solids, and to which the supernatant from the separatory funnel and centrifuge tubes were returned, was vigorously shaken to resuspend and homogenize any residual particulate matter. Subsamples (in triplicate at least initially) of ~50 mls were removed for filtration through 0.4 µm polycarbonate filters and subsequent analysis of particulate and dissolved mercury. Three replicate filters and corresponding filtrates were prepared. Membranes containing the collected suspended phases were stored frozen until analyzed while the filtrate was acidified to pH 2 using concentrated HNO_3 and stored for analysis.

The solid fraction in the centrifuge tube was dried to constant weight at room temperature, removed and ground to a uniform consistency. Subsamples of this material were analyzed in replicate for mercury as described later. The subsamples of the combined liquid phases were filtered though 0.4 µm polycarbonate membranes. Both the membrane-retained material and filtrate were analyzed for mercury as described below.

At the end of the field experiments, the amalgam accumulated by the tested amalgam removal technologies was removed where possible and analyzed as described for the solid phase below. Sufficient replicate samples were analyzed to achieve a precision of $\leq$ 10%.

Sample Analysis

The filtrate and membrane filters were analyzed using EPA protocols (EPA Method 245.1) **after** microwave-assisted digestion of the filters (Wallace et al., 1991). Verification of completeness of recovery from the filters was confirmed by performing a second digestion of the same digestion containers after transfer of the original digestate. The mercury concentrations in the redigestates of the filter containing samples were not significantly different from those of the procedural blanks.

After homogenizing the settleable solid samples, replicate 100 mg samples, if sample size permitted, were digested using the same microwave digestion technique used to prepare the filter samples. Sample sizes as small as a few mg were analyzed *in toto* when only small amounts of settleable solids were recovered. Completeness of the recovery of mercury from the amalgam solid digestates was confirmed by digestion of scrap amalgam of known composition. Recovery of mercury from the amalgam reference material was 93 ± 12 % (N = 9). If one outlier is excluded, the recovery of mercury from the amalgam reference material becomes 97 ± 5 % (N = 8).

This technique provides complete and total dissolution of a variety of matrices including sediment and a variety of organic tissues. We have successfully participated in a number of national and regional intercalibration exercises using both sample types. Sufficient replicates were run to assure a precision of generally better than 10%. Our precision in the recent analysis of a standard reference sediment sample (PACS-1 prepared by the Canadian Research Council) containing 4.57 ug/g dry weight of mercury was ± 2% with a recovery of 101%. Independent checks on the calibration curves used to standardize the Mercury Analyzer were conducted using certified aqueous standards.

Procedural blanks of deionized water were carried through the entire procedure as well as reagent blanks for all the types of analyses performed. Standard or secondary reference samples and blanks were prepared at frequency of at least 10% of the samples. All blank and recovery data are reported in Appendix B. Replicates were also run at the same minimum frequency or higher.

Data Reduction

All data from the Mercury Analyzer were electronically recorded and transferred into an Excel spreadsheet in a standard format. These data were used to calculate the concentration of the various media analyzed. For each sample, the concentration of the sample (aqueous or solid) was calculated. The data were then used with the volume collected, where available, to determine the total mass flux of mercury at each facility after treatment by the installed mercury amalgam removal. Because of the time interval of collection over five days and the subsequent processing time (several days), the suspended and dissolved mercury values may not accurately represent the original suspended and dissolved fractions of mercury in the samples. We made no attempt in this work to assess the possibility of post-collection transformation before separation of the suspended and dissolved phases in the laboratory. However, the relative proportion of solids to aqueous phases of mercury, especially in the daily samples if collected, may provide at least an approximation of the relative importance of the two phases.

These data was compared to data obtained from the bench testing of identical units. As noted earlier, data derived from the literature or other unpublished results are included in the analysis when review of the data warrant. We examined the data for its analytical quality (proper method validation and reporting), and comparability (identical system, use in similar dental facility, etc.). Method validation is based on reported performance on standard reference materials, data on the frequency, precision and magnitude of procedural blanks and replicates, and, if EPA standard methods were not used, a description of the method used. By inclusion of such data we hope to extend the comparison to those vendor units not installed in the immediate Boston area but which we are able to bench test using the above protocol. A number of the units we will be testing will have already been tested using the ISO protocol. Results of the laboratory bench-test results using the protocol developed in this work will be compared to the data on ISO bench test results of identical units in Part II of this report. This will provide further linkage to past assessments of performance using independent protocols.

Results

Field Observations

The results of the analyses of the field samples collected from four dental facilities, herein designated as Sites A, B, C, and D, each of which was using a different mercury amalgam collector. The facility at Site A was a two chair dental office with existing plumbing that restricted options with respect to placement of the separator. The technology at this site consisted of a sedimentation trap coupled with a resin designed to remove non-settleable mercury as it passed through the unit. It was placed in line under vacuum before the air-water separator and residence time of the wastewater was a function of the rate of water use released from the facility. Flow at this site was low and the entire week's discharge could be captured in a 20 l carboy. Reported dental procedures involving amalgam (removal and/or placement) were weighted by the size of the procedure as shown in Appendix A, Table 1. Assuming the reporting forms were complete and accurate, the mean weighted activity involving amalgam at this site was 1.6 procedures/dentist/day.

Samples at this site were necessarily collected at a point after the air-water separator and not immediately after the amalgam separator. Thus mobilization of residual mercury located in the pipe and air-water separator downstream of the separator may have contributed to the mercury observed in the collected samples. We recognized this potential problem and offered to move our sampling location to one of the other facilities in which this vendor had placed similar systems. The offer was not accepted. In an attempt to examine the extent of the "contamination" of the samples from this possible source, we flushed the pipes with about 5 liters of deionized water and then a second 5 liters on two separate occasions. The discharge of the second 5-liter rinse was collected and then processed and analyzed in the same way as an effluent sample. As discussed below, the mercury concentrations in these samples were substantial and make interpretation of the results from this site tenuous at best. The results, however, do emphasize the need to carefully consider the placement of any amalgam system in the waste discharge system, a point discussed more fully below.

Site B was a relatively new facility with four dentists and an amalgam separator designed to capture the wastewater generated each day in the air-water separator and then treat the volume of wastewater produced at night at a flow rate controlled by a peristaltic pump. The wastewater was passed at a flow rate of about 126 mls/minute through a sedimentation compartment and then through an ion exchange resin after preoxidation of the sample using bleach. The latter procedure is necessary to convert any mercury passing through the sedimentation tank to a chemical form extractable by the resin. Unfortunately the bleach supply used in the treatment process was not maintained over the first 12 weeks of sampling. The results for this period therefore reflect the ability of the technology to remove mercury by sedimentation and of readily extractable mercury by the resin. Chemical forms not available for exchange at the active resin sites (suspended fine particles escaping the sedimentation chamber, colloidal, and non-labile organic complexes) were therefore not removed and collected in the effluent.

A solid-phase controlled-release source of bleach was then installed and sampling of the effluent continued for an additional six weeks. An automated ISCO sampler was used to subsample the flow released each night and combined to form a weekly composite sample as before. Procedures involving mercury amalgam (removal only as no mercury amalgam installations occur at this site) averaged 2.0/dentist/day (Appendix A, Table 2). However two of the dentists operating at this site failed to report their activity after week 3. Thus while the weekly procedure/dentist activity may be accurate over the first three weeks at this site, the total level of activity at this facility is an underestimate.

The amalgam separator located at Site C was an in-line sedimentation device. Sampling was conducted immediately downstream of the device and samples were collected using an ISCO sampler. The dentist at this site performed a weighted average of 2.4 procedures/dentist/day that involved mercury amalgam. It was not possible to obtain an accurate estimate of the volume of wastewater produced at this site.

The final site (Site D) was a dental facility with four practicing dentists equipped with an amalgam separator designed to store the wastewater discharged on a daily basis and then process the wastewater after release of the vacuum overnight. Wastewater trapped in the holding tank was fed by gravity through a sedimentation chamber and the effluent then discharged. This unit is designed to be placed at the wastewater discharge outlet of the air-water separator. However due to space limitations the separator had to be placed in the vacuum line rather than at the outlet of the air-water separator. Sampling at this location did, however, occur at the discharge point of the amalgam separator. It is also important to note that while the sedimentation chamber of this unit was replaced with a new unit at the beginning of the sampling period, the holding tank was not replaced; nor was the holding tank cleaned prior to the onset of sampling. Thus any residual material held in the holding tank might have been mobilized into the sedimentation chamber. Samples at this site were collected by ISCO sampler.

On several occasions daily samples were taken to capture the entire flow allowing a limited estimate of the discharge flux of mercury to be made at this site. The weighted average number of procedures/dentist/day involving mercury at this site was 1.1. Sporadic gaps in reporting make the total level of activity at this site an underestimate.

Sample Processing and Analysis

Samples from all four sites were processed to separate each into three fractions as described above. Each of the three fractions, settled solids, suspended, and dissolved, were then suitably analyzed for mercury after oxidation and digestion using the procedures described above. Procedural blanks, recovery of mercury from a mercury amalgam of known composition, the precision of replicate analyses of the same sample, and the precision of replicate samples are given in Appendix B. Generally, procedural blanks were negligible compared to the sample concentrations analyzed. Analytical precision based on replicate analysis of the same sample for all samples was typically 2.4 ± 4.2 % (N = 90) (expressed as the relative standard deviation or %RSD). The precision of determinations of dissolved concentrations in replicate samples was 6.3 ± 8.1 % (N = 40) and that for the analysis of replicate particulate samples 26 ± 23 % (N = 53). Mean precision in the determination of replicate solids samples was 9 ± 10 %. Recovery of mercury from the amalgam reference material was 93 ± 12 % (N = 9). With one outlier excluded, the recovery of mercury from the amalgam reference material becomes 97 ± 5 % (N = 8).

We attribute the larger uncertainty in the particulate samples to the difficulty in obtaining a homogeneous subsample from the solids sample supernatant, particularly from samples with large solids fractions. This observation and the labor-intensive nature of efforts to separate the solids by “vacuuming” them from the bottom of the containers suggest the following changes be made in the separation of settleable solids. After settleable solids are allowed to accumulate overnight, the majority of the supernatant (rather than the settled solids) would be removed using a peristaltic pump. The remaining supernatant and solids (volume less than 250 mls) would then be quantitatively transferred to 250 ml separation funnels with large bore stopcocks and allowed to settle overnight. The resultant solids are withdrawn from the bottom of the separatory funnel and then centrifuged and processed as above. The supernatants would be combined with the supernatant fraction collected earlier. The combined supernatants would then be mixed by shaking and the suspended matter and dissolved fractions separated by filtration through 0.4 µm filters as described above. We expect this procedure would provide for a more homogeneous supernatant containing smaller particle sizes than the procedure used in this work.

Effluent Concentrations

The effluent from site A frequently contained >mg/l quantities in the particulate fraction and ranged from 1.2 to 33 mg/l in the solid fractions analyzed (Table 4 – Site A). An exceptionally high particulate concentration was observed in week 4 (17.7 mg/l) that was an order of magnitude above the remaining particulate concentrations. We have calculated the mean weekly concentrations using all of the data for all of the fractions and the resulting total. We also present for consideration alternate means where anomalously high values in a given fraction skew the original result. These "alternative" means probably represent a more realistic estimate of the performance of the technologies on a week-to-week basis with the relatively rare higher values representing episodic excursions resulting from a number of unknown variables. The sample concentrations not used in calculation of the alternate means are well above three times the standard deviation of the alternate sample mean, a measure sometimes arbitrarily used to indicate outliers in a population. However there is no rigorous statistical justification for excluding these samples and the data are for that reason included in the mean values reported.

As noted earlier the separator at this site is located in the discharge line of the drainage pipe before the air water separator. It was not possible to clean the pipes and air-water separator between the unit and point of collection. To establish the potential contribution of residual amalgam deposited in the pipes and air-water separator downstream of this unit, we flushed the pipes leading to the separator with several liters of deionized water and then released an additional several liters of deionized water down the system with the unit bypassed. If there was a negligible concentration of mercury in the second batch of deionized water we could be relatively confident that the results would not be biased by release and capture of residual mercury in the pipes and air-water separator downstream of the unit.

Unfortunately, there was substantial amount of mercury in all fractions as shown at the bottom of Table 4 where the results of the analyses of the deionized water flushes are presented. The results for this site are therefore questionable as an indicator of treatment capability of the separator installed as they may have been influenced by potential mobilization of mercury in the pipe and air-water separator downstream of the unit. This site is particularly sensitive to this problem in that the dentist's practice is to use very small quantities of distilled water in his everyday practice. Total water use in this office amounts to about 2 liters per day. The small volume flushed down the pipes would exacerbate the potential for storage in the pipes and air-water separator.

We believe the placement of the unit in the system is a critical factor resulting in the failure to realize the full potential of the amalgam separator installed at Site A. The results however accurately reflect the capability of the unit as installed. It is quite obvious that the placement of any amalgam separator technology, here or elsewhere, where the goal is effluent quality and not efficiency of removal, is a critical variable. Installation of amalgam separators in systems where preexisting "contaminated" components remain downstream would result in an inability, regardless of their intrinsic removal efficiency, to produce low-mercury effluent. For that reason we make the following recommendation.

TABLE 4 - SITE A

Week #	Mean Dissolved (ug/l)	Std Dev Dissolved (ug/l)	Mean Particulate (ug/l)	Std Dev Particulate (ug/l)	Mean Settleable (ug/l)	Std Dev Settleable (ug/l)	Total (ug/l)	
1				No Sampling				
2				No Sampling				
3				No Sampling				
4	144.5	143	17716	4124	33331	906	51191	**Notes 1 & 3**
5	880.7	34.5	406		27895	5458	29180	**Notes 2 & 3**
6	107.5	13.4	1194	150	1168		2470	
7	69.2	30.7	80	34	6785	2595	6935	
8	86.8	4.1	2362	136	7641	208	10090	
9	38.4	6.8	187	68	3280		3506	
10	58.0	16.3	574	152	1712		2344	
11	64.6	5.4	1301	78	1217		2583	
12	131.7	12.6	452	76	2575	62	3159	
Mean	**176**	**267** **152%**	**2697**	**5677** **211%**	**9512**	**12260** **129%**	**12384**	**16890** **136%**
Alternative Means	**88**	**37** **43%**	**819**	**762** **93%**	**3483**	**2667** **77%**	**4441**	**2955** **67%**

Note 1 Removed to calculate Alternative Mean for Particulate data
Note 2 Removed to calculate Alternative Mean for Dissolved data
Note 3 Removed to calculate Alternative Mean for Settleable Solids data

Pipe Flush*	42.2	4.5	621	84	15816		16479

* This sample was collected from the sample collection point used throughout except that the amalgam removal apparatus was by-passed.

Recommendation:

Amalgam separators installed in facilities with preexisting waste conveyance systems should be placed, if feasible, at the furthest point downstream in the amalgam wastewater discharge piping within the facility ((i.e. at or near the point of release from the dental facility). Separators placed in line and releasing treated water into preexisting mercury-contaminated drainpipes and air-water separators within the facility cannot achieve optimal effluent quality and will lead to a release of mercury that could otherwise be avoided. Cleaning of downstream pipes and air-water separators before installation is highly recommended if feasible.

Total mercury over the 9 week period at Site A suggest that the average concentration of mercury released at this location is 12.4 ± 16.9 mg/l. If the very high concentrations of mercury observed for weeks 4 and 5 are excluded, the average concentration becomes 4.4 ± 3.0 mg/l. The flux of mercury from this site is 30 ± 39 mg/day/dentist using all of the data and, and if the same two high concentrations in the flux estimate are excluded, is reduced to 11 ± 8 mg/day/dentist. These estimates, as are all following estimates of this type, dependent on the thoroughness of reporting as well as sample variability. The value of estimates reported in terms of the frequently used mercury/dentist/day unit is difficult to assess, as both the work schedule involving amalgam procedures and the effluent data was quite erratic. The high and low flux estimates, when compared to the estimated 400 mg/dentist/day passing chairside traps discussed earlier, represents removal efficiencies of 93 and 97 % respectively.

The amalgam separator in the facility at Site B is located after the air-water separator and just prior to the point of discharge into the sewage system and avoids the installation problems observed at Site A. For reasons discussed earlier the results reported here in Table 5 for the first ten weeks do not necessarily reflect the full potential of this unit

Mercury concentrations in all fractions were relatively low and reasonably consistent even without proper addition of the oxidizer. However, concentrations in the dissolved fraction were the highest of the three fractions perhaps reflecting the absence of the oxidant release during the initial sampling period discussed here and/or the low pH of the effluent (2.4 ± 0.3, N = 8). Results obtained in the second round of sampling at this site are not significantly different from the earlier set despite the remedial actions taken to ensure a consistent supply of oxidant. We speculate that the failure to maintain an adequate supply of oxidant in the earlier trial may have led to irreversible fouling and deactivation of the ionic mercury removal capability of this unit. In addition the acidic conditions of the wastewater (see below) may also have reduced the efficiency of the ion exchange resin used. Nevertheless, the overall mean total concentration observed over the 16 weeks of operation was 0.54 ± 0.15 mg/l. Over half of the mercury released at this site was in “dissolved” form.

Effluent volume produced at this site exceeded that which we could collect on a weekly basis. We therefore turned to examination of the limited data we obtained from

Table 5 - Site B

Week #	Mean Dissolved (ug/l)	Std Dev Dissolved (ug/l)	Mean Particulate (ug/l)	Std Dev Particulate (ug/l)	Mean Settleable (ug/l)	Std Dev Settleable (ug/l)	Total (ug/l)	
1				No Sampling				
2	232	27	114	52	Sample Lost		>346	
3	168	4	152	15	4.1		324	
4	179	3	78	10	0.0		258	
5	523	14	196	103	0.0		718	
6	264	13	136	36	71.6	0.3	472	
7	430	169	182	12	-0.0		613	
8	240	36	200	39	50.7		490	
9	286	6	164	21	9.2		460	
10	601	3	177	7	0.3		779	
11	300	12	52	7	215.8	11.0	577	
12	309	27	190	35	5.7		505	
A	380	5	35.1	9.2	0.0		415	
B	458	18	23.6	0.5	0.0		481	
C	479	6	14.6	5.0	0.0		494	
D	532	7	25.4	1.3	0.0		557	
E	689	6	148.7	2.6	0.0		837	
F	547	41	88.1	5.2	0.0		635	
Weeks 1-12	**321**	**139**	**149**	**49**	**32**	**68**	**519**	**161**
		43%		**33%**		**209%**		**31%**
Weeks A-F	**514**	**104**	**56**	**52**	**0**	**0**	**570**	**151**
		20%		**94%**				**26%**
Overall Mean	**389**	**157**	**116**	**67**	**22**	**56**	**538**	**154**
		40%		**58%**		**249%**		**29%**

those sites where total volume released were available and the data obtained from the MCES/MDA (2001) report. Our observations at only two sites indicated an average release of 2.6 L/dentist/day at both sites while that from the Minnesota report for 7 sites was 4.7 ± 2.0 L/dentist/day. We use the average of these two data sets to estimate a mean flow of 4.4 ± 2.0 L/dentist/day. This estimated average flow was then used to calculate an estimated flux of ~ 0.59 mg/dentist/day at Site B. If we assume an average loading of 400 mg/dentist/day as described earlier, an apparent efficiency of removal at Site B is estimated to be 99.85%.

The amalgam separator technology installed at Site C uses an inline sedimentation device to remove solids remaining after removal of larger amalgam particles by a 7 mm mesh-size screen placed immediately upstream of the unit. As noted earlier this separator is designed to remove mercury associated with particles in a flow-through mode with flow rate, and hence residence time, of the wastewater in the unit determined by rate of use of water in the facility. Flows were again too large to capture an entire week's effluent at this site and logistics prevented obtaining a significant number of daily samples.

With one notable exception, dissolved and particulate fractions were reasonably consistent over the 9 weeks over which complete data was obtained (Table 6 – Site C). Dissolved mercury concentrations were the lowest observed at all the sites tested, especially if one data point, week 7, is not used to calculate the mean (see alternate mean dissolved data in Table 6). This one sample was also anomalous in its particulate concentration as well for unknown reasons. The mean total mercury concentrations observed was 0.97 ± 1.21 mg/l. The alternative mean was 0.33 ± 0.27 mg/l. Using the mean flow estimated above of 4.4 ± 2.0 L/dentist/day, and the average effluent concentration calculated from the data from this site in Table 6, we estimated a flux of ~4.3 mg/dentist/day and assuming an average loading of 400 mg/dentist/day as described earlier, the efficiency of removal at Site C is estimated to be 98.94%. Use of the alternate mean produces a flux of ~ 1.47 mg/dentist/day for an apparent efficiency of 99.63%. Data for samples collected from the effluent of the separator installed at site D is presented in Table 7 – Site D. The technology used is designed to capture the daily wastewater discharge and process the captured wastewater overnight after shutdown of the vacuum system. Weekly sample volumes were again too large to capture the effluent volumes produced and consequently most of the samples were collected as composite samples collected over a one-week period. However, on several occasions samples were collected overnight to capture the entire volume released. Sample characteristics were not significantly different from those of the weekly samples.

Mercury concentrations in the solids fraction were generally low (<125 ug/l) over the last 6 weeks of the sampling period. However two of the weekly composites were collected during times when most of the dentists were on vacation and no procedures involving mercury were reported on the dentist's activity reports. The finer particles represented by the suspended particulate fraction concentration values were somewhat higher in concentration than those in the solids fractions. However, the major fraction of mercury in this effluent appeared in the dissolved mercury fraction with concentrations

Table 6 - Site C

Week #	Mean Dissolved (ug/l)	Std Dev Dissolved (ug/l)	Mean Particulate (ug/l)	Std Dev Particulate (ug/l)	Mean Settleable (ug/l)	Std Dev Settleable (ug/l)	Total (ug/l)			
1				No Samples Taken						
2				No Samples Taken						
3	18	5	176	163	589		783	**Note 2**		
4	9	3	725	256	1562	66	2295	**Note 2**		
5	13	3	1159	1010						
6	8	1	162	10	19	21	188			
7	285	351	3282	983	58		3624	**Note 1**		
8	12	6	799	69	24		834			
9	7	1	358	59	3		368			
10	9	6	303	31	48		360			
11	5	2	200	11	6		211			
12	9	4	18	3	14		40			
Mean	**37**	**87**	**718**	**968**	**258**	**524**	**967**		**1206**	**Note 3**
		233%		**135%**		**203%**			**125%**	
Alternative Means	**9.9**	**3.9**	**433**	**377**	**24**	**21**	**334**		**274**	**Note 4**
		39%		**87%**		**85%**			**82%**	

Note 1 Removed to calculate Alternative Mean for Dissolved and Particulate data
Note 2 Removed to calculate Alternative Mean for Settleable Solids data
Note 3 Total excludes Week 5 as no Settleable Solids data available for this week.
Note 4 Alternative Mean excluding data from weeks 3,4 and 7.

Table 7 - Site D

Week #	Mean Dissolved (ug/l)	Std Dev Dissolved (ug/l)	Mean Particulate (ug/l)	Std Dev Particulate (ug/l)	Mean Settleable (ug/l)	Std Dev Settleable (ug/l)	Total (ug/l)	
1				No Samples Taken				
2	1121	181	678	274	Sample Lost			**Note 1**
3	1013	14	129	63	429		1571	
3'	1684	35	84	19	309		2077	
4	1458	32	176	81	350		1984	
5					11383	387		**Note 1**
6	2137	60	176	70	25		2338	
7	1231	39	168	167	58		1458	
8	733	41	86	57	0		819	
8'	667	31	69	8	1.3		737	
9	1866	27	221	10	24		2111	
9'	1613		297		124		2033	
10	1255	26	35	2	2.7		1292	
11				No Samples Taken				
11'	1529	30	94	14	3.4		1626	
12	1188	53	71	42	3.4		1260	
' Indicates second sample taken that week.								
Mean	**1346**	**426**	**176**	**168**	**111**	**158**	**1609**	**518**
		32%		**95%**		**143%**		**32%**

Note 1 Removed to calculate mean for Settleable Solids and Total data. Week 2 samples lost during processing. Average Settleable Solids concentration excludes anomalous week 5 sample in which only 79 mls were collected.

consistently exceeding 1 mg/l, the highest observed at any of the sites. We suspect that the low pH of these samples (2.7 ± 0.8) coupled with a long residence time before processing in the amalgam separator produce the anomalously high dissolved values. The release of substantial quantities of mercury, even when no procedures involving mercury were reported, may be due to remobilization of mercury from the solids captured and stored in the separator by use of the acidic cleansers. Also, although no quantitative measurements were made to verify this observation, the particle size of the trapped amalgam recovered from the separator at the end of the field work appeared to be finer than that obtained from the separators at two of the other sites. The fine particle size and resultant large particle surface to volume ratio would enhance dissolution at low pH. As noted below, we suspect that were the pH to be kept near neutral, the dissolved mercury concentrations could be much lower.

We believe the differences in dissolved mercury concentrations at each of the sites can largely be explained by differences in the mean pHs of the effluent (Table 8).

Table 8

Site	Dissolved Mercury (µg/l)	pH
A	180 ± 270, N = 9	2.4 ± 0.3, N = 8
B	390 ± 160, N = 17	2.7 ± 0.4, N = 10
C	40 ± 90, N = 9	7.3 ± 0.7, N = 11
D	1340 ± 430, N = 13	2.7 ± 0.8, N = 13

For example effluent pH at Site B was 2.7 ± 0.4 while that at Site C was 7.3 ± 0.7). It is common knowledge that the aqueous solubility of most metals is enhanced at acidic pHs. Despite requests made of all dental facilities participating in this study to avoid the use of acidic line cleansers, the pH of effluent collected at all sites other than at site C generally fell between 2 and 3 (Table 8).

Effluent dissolved mercury concentrations with acidic pHs were ~5 to 36 times greater than that observed under neutral pH conditions. It is of interest to note that at site C, despite the use of a technology designed only to remove particulate matter, dissolved mercury concentrations ranged between 5 and 18 µg/l with one exception. While the sample size is small we feel the results indicate a clear need to maintain the pH of the wastewater at neutral or slightly basic levels to avoid enhanced dissolution of mercury from solids in the wastewater. This is of particular importance where the residence time of the wastewater is longer such as in the two capture and treat technologies used in sites B and D. Also enhanced proton (H^+) competition at low pH with active mercury binding sites on mercury sorption resins can be expected to reduce the efficiency of the sorbents used to remove mercury. We do not know the reason for variation of the dissolved levels at similar pHs but it is reasonable to assume other variables such as residence time, surface to volume ratios and other solution variables (nature and type of complexing agents present, etc.) may be expected to influence the dissolved concentrations in amalgam separator effluents. Based on this observation we make the following recommendation.

Recommendation:

It is well known that acidic pHs will solubilize mercury, as well as most metals in the amalgam, copper pipes and other solid phases in contact with the wastewater. The use of acidic cleansers or other processing of the wastewater discharged from facilities that produce acidic pHs must be eliminated if maximum removal by amalgam separators is to be realized.

Comparison of Mercury in Effluent With ISO Removal Efficiencies

Recently, Fan et al. (2002) have reported the removal efficiencies of the units tested in this research using the ISO 11143 standard protocol. We compare our estimated efficiencies of removal with those reported by Fan et al. (2002) in Table 9 for the units used at each site. There is generally good agreement between the two independent estimates.

Table 9

Site	Fan et al. (2002)	This Work
B	99.96	99.85
C	97.84	98.94
D	99.67	99.74

We then compared the effluent quality measured in this work as a function of the solids removal efficiency reported by Fan et al. (2002). We plot both the total mercury concentration in the effluent as well as just the sum of the particulate and settleable solids concentration against efficiency in Figure 3. The open circles in Figure 3 are the total concentration data while the solid squares represent the sum of the particulate and settleable solid fraction concentrations. There is an encouraging fit of the latter data to removal efficiency suggesting that ISO testing results may be a reasonably good predictor of the removal of solid phase mercury. On the other hand the plot also illustrates the inability of the ISO test to predict total mercury removal when dissolved phases are present. While the above results are encouraging, a more robust relationship between field and laboratory assessment of mercury removal has still to be developed. We investigate in Part II of this report whether a relatively inexpensive and simple alternative to the ISO 11143 Protocol will produce results comparable to the ISO test results for the units in this work. If so there may be a rapid and inexpensive alternative to predict the effluent quality with respect to solid phase mercury using amalgam separators. The inability of the ISO test to predict effluent quality with respect to the release of colloidal and dissolved mercury would remain however.

The data in Figure 3 also suggest the magnitude of the required resolution of techniques assessing the efficiency required to reduce solid phase mercury to reach levels on the order of 100 ug/l mercury in the effluent, at least with respect to solid phase mercury concentrations. Resolution on the order of 0.1 % at efficiencies above 99.5% would be required to develop a predictive capability at this order of magnitude. Based on the regression in Figure 3, each 0.1 % change in efficiency would be equivalent to a change in mercury effluent concentration of ~ 40 ug/l. At an efficiency of 95%, mercury concentrations as suspended and settleable solids would be on the order of 2 mg/l if the regression in Figure 3 could be extended to lower efficiencies. The practical limits of the existing ISO test are quite evident.

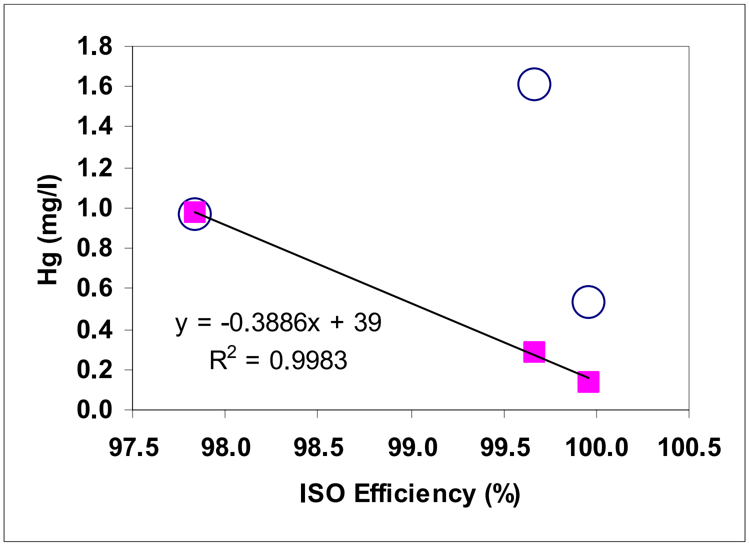

Figure 3. Hg concentrations in effluent vs. ISO efficiency. Open circles indicate total mercury concentrations while squares represent the sum of the particulate and settleable solid fractions.

Of the four amalgam separators tested, two were designed to treat the wastewater generated in real time in a flow-through mode. As such, given the known variability of the waste stream from dental facilities, they face a greater challenge in removing mercury from the waste stream then separators that capture and treat the wastewater under more controlled conditions. We use the following example to make this point. Assume that the ISO determined operating efficiency of a separator is 95%, the volume treated in a day is about 10 liters, and there are 2 dentists operating in the facility. Challenged with an estimated average discharge flux of about 0.4 g/dentist/d, equivalent to a mean concentration of 80 mg/L in the 10 L discharge, one might expect a discharge concentration of 0.05 x 80 mg/L = 4 mg/L. Now, rather than adopting the assumption of a constant flux during the 10 L discharge, assume that the majority of the discharge is released in a much smaller volume during the actual procedure. Assume for example that 90 % of the mass discharged is in an initial volume of 2 L rather than in 10 L. The resulting effluent concentration after treatment, assuming the same constant efficiency of 95%, would be 20 mg/l. This illustrates the potential sensitivity of a separation technology operating on a highly variable waste stream at an assumed fixed efficiency.

In contrast, separators that capture the daily flow, such as that used at sites B and D in this work are able to process the effluent over a longer time period allowing much longer residence times for settling in the sedimentation compartment of the separator. Obviously, the ability to increase the residence time used to further treat the wastewater after removal of settleable solids is also desirable. Chemical conditioning to remove the fine particle, colloidal and dissolved fractions such as that used in the technology at site B can be kinetically slow and thus benefit from an extended residence time under controlled flow rates. It is not surprising that the two lowest mean settleable solids concentrations were observed in technologies using this capture and treat approach. This discussion leads us to our third major recommendation.

Recommendation:

In conjunction with recommendation #1, the treatment capacity of the technology installed should a) be appropriately sized to accommodate the volume of effluent produced, and b) be able to function effectively across the well-documented variability of the waste water characteristics being treated. Technologies that are designed to capture, temporarily hold and then treat the wastewater using appropriate flow rate control methods are therefore most likely to produce effluents with consistently low concentrations and mass fluxes of mercury. The amalgam separator should be located so that it will not unnecessarily treat large volumes of uncontaminated water. A corollary to this recommendation is that water usage in dental facilities be minimized to facilitate the use of such capture and treat technologies.

CONCLUSIONS

In summary while some of the data indicate episodic excursions in concentrations, especially in those treating the wastewater in a flow-through mode, the field sample results provide relatively consistent data reflecting the design and functioning of the units under actual field use conditions. Appropriate design sizing of the amalgam technologies and proper installation would, we feel, generally provide reliably consistent removal of the bulk of the mercury released from dental facilities. We also believe that much lower levels than observed here could be readily achieved with little increase in cost of the technologies used in this study if the recommendations above were to be adopted in the design, placement and operation of the technologies.

In addition, even though the duration of this study was perhaps longer than any conducted previously, there is no knowledge base supporting assessment of the long-term performance of these technologies in the field as also noted in the MCES/MDA (2001) report. Proper maintenance and monitoring should be conducted until such a knowledge base is established to support management decisions on setting target concentrations and fluxes in the future. Sampling reinitiated at one of the sites after a period of 29 weeks produced results comparable to those observed in the initial 12 week sampling period. Additional data on Amalgam separation technology performance over the manufacturers stated lifetimes and maintenance intervals should be confirmed by appropriate long-term monitoring efforts. This is expected to be particularly important to confirm performance of advanced and more complex technologies directed towards removal of fine particulate, colloidal and dissolved mercury. Proper long-term operation of these more advanced technologies is likely to require a more rigorous maintenance and operating schedule.

In the meantime, based on the evidence gathered in this study and those conducted elsewhere, the use of amalgam separators coupled with well-planned placement of the separator in the facility's waste disposal system and the use of effective best management practices, would substantially reduce the release of mercury in the effluent from such facilities.

The critical variables impacting the performance of the various units in this study and in others as well are most likely the conceptual design of the system (e.g. "capture and treat" vs. "flow-through"), placement of the system in the facility, and control of the pH (primarily through use of non-acidic cleaners) of the effluent. It is also apparent that the ISO test alone is not necessarily a good predictor of mercury effluent in the waste stream from dental facilities that employ amalgam separators due to other variables affecting the technology's performance as indicated above. Furthermore greater sensitivity in assessing solids removal capabilities of amalgam separators will probably be required to resolve performance at removing mercury to concentrations of 1 mg/L and less that requires removal efficiencies greater than 99%. Thus we make the following final recommendation. Assessment of amalgam separators capabilities to achieve even lower effluent concentrations may require more comprehensive testing such as that conducted here.

Recommendation:

The ISO amalgam separator test, although providing useful information, should not be the sole basis for decisions regarding the effectiveness or acceptability of these technologies. It is recommended that the ISO test (or appropriate bench scale alternative) serve only as a base component in any certification program or other decision-making process regarding these units. Additional factors that might be considered include the availability of field test data demonstrating effectiveness in actual clinical settings, verification of the adequacy of recommended servicing and maintenance schedules, vendor specifications regarding the sizing of the units for particular office applications (see Recommendation #3 above), adequacy of installation instructions to ensure that units are placed appropriately, and evidence that the technology will not substantially increase dissolved mercury discharges.

Part II of this report will report the results of the laboratory bench test protocol using these same technologies and a publication including both parts will be forthcoming.

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Appendix A

Table 1 - Site A Dental Activity

SITE A Week	Removal			Installation			Both			Totals			Unweighted TOTAL	Weighted Totals*	Weighted Totals per Dentist**
	L	M	S	L	M	S	L	M	S	L	M	S			
5	1	10	0	2	9	1	0	0	0	3	19	1	23	16	16.0
6	0	3	0	0	4	0	0	0	0	0	7	0	7	5	4.7
7	0	2	2	0	2	3	0	0	2	0	4	7	11	5	5.0
8	1	0	0	1	0	0	0	0	0	2	0	0	2	2	2.0
9	0	2	0	0	2	0	0	0	0	0	4	0	4	3	2.7
10	0	0	0	0	3	0	3	3	0	3	6	0	9	7	7.0
11	2	1	0	2	2	0	1	0	2	5	3	2	10	8	7.7
Total	**4**	**18**	**2**	**5**	**22**	**4**	**4**	**3**	**4**	**13**	**43**	**10**	**66**	**45**	**45**
Avg/wk	**0.6**	**2.6**	**0.3**	**0.7**	**3.1**	**0.6**	**0.6**	**0.4**	**0.6**	**1.9**	**6.1**	**1.4**	**9.4**	**6.4**	**6.4**
Avg/d															**1.6**

* Weighted number of procedures were calculated using the formula: Weighted # of procedures = [(3/3 x # large) + (2/3 x # medium) + (1/3 x # small)]

** Weighted number of procedures divided by the number of dentists reporting activity.

Appendix A

Table 2 - Site B Dental Activity

SITE B Week	Removal			Installation			Both			Totals			Unweighted Total	Weighted Totals	Weighted Totals per Dentist
	L	M	S	L	M	S	L	M	S	L	M	S			
1	27	33	11							27	33	11	71	53	13.2
2	21	24	9	No Installation data						21	24	9	54	40	10.0
3	9	16	5	submitted by this office						9	16	5	30	21	5.3
4	11	14	0							11	14	0	25	20	10.2
5	5	5	1							5	5	1	11	9	4.3
6	6	6	0							6	6	0	12	10	5.0
7	6	14	6							6	14	6	26	17	8.7
8	11	10	4							11	10	4	25	19	9.5
9	15	11	2							15	11	2	28	23	11.5
10	6	6	5							6	6	5	17	12	5.8
11	24	13	7							24	13	7	44	35	17.5
12	10	8	6							10	8	6	24	17	8.7
Total	**151**	**160**	**56**	**0**	**0**	**0**	**0**	**0**	**0**	**151**	**112**	**32**	**229**	**170**	**57**
Avg/wk	**12.6**	**13.3**	**4.7**							**12.1**	**16.0**	**4.6**	**32.7**	**24.3**	**8.1**
Avg/d															**2.0**

Note: Two dentists stopped reporting after Week 3

* Weighted number of procedures were calculated using the formula: Weighted # of procedures = [(3/3 x # large) + (2/3 x # medium) + (1/3 x # small)]

** Weighted number of procedures divided by the number of dentists reporting activity.

Appendix A

Table 3 - Site C Dental Activity

SITE C Week	Removal			Installation			Both			Totals			Unweighted Total	Weighted Totals	Weighted Totals per Dentist
	L	M	S	L	M	S	L	M	S	L	M	S			
2	3	1	2	4	2	4	1	0	0	8	3	6	17	12	12.0
3	3	3	0	2	2	2	0	0	0	5	5	2	12	9	9.0
4	6	5	4	6	5	6	0	0	0	12	10	10	32	22	22.0
5	2	3	2	4	2	2	0	0	0	6	5	4	15	11	10.7
6	2	4	1	2	6	3	0	0	0	4	10	4	18	12	12.0
7	5	2	0	5	2	5	0	0	0	10	4	5	19	14	14.3
8	5	0	0	4	0	0	0	0	0	9	0	0	9	9	9.0
9	2	1	0	2	0	1	0	0	0	4	1	1	6	5	5.0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
11	0	0	1	1	2	0	0	0	0	1	2	1	4	3	2.7
12	2	2	0	3	2	5	0	0	0	5	4	5	14	9	9.3
Total	**30**	**21**	**10**	**33**	**23**	**28**	**1**	**0**	**0**	**64**	**44**	**38**	**146**	**106**	**106**
Avg/wk	**2.7**	**1.9**	**0.9**	**3.0**	**2.1**	**2.5**	**0.1**	**0.0**	**0.0**	**4.7**	**4.0**	**3.5**	**13.3**	**9.6**	**9.6**
Avg/d															**2.4**

* Weighted number of procedures were calculated using the formula: Weighted # of procedures = [(3/3 x # large) + (2/3 x # medium) + (1/3 x # small)]

** Weighted number of procedures divided by the number of dentists reporting activity.

Appendix A

Table 4 - Site D Dental Activity

SITE D Week	Removal			Installation			Both			Totals			Unweighted Total	Weighted Totals	Weighted Totals per Dentist
	L	M	S	L	M	S	L	M	S	L	M	S			
1	15	5	2	0	0	2	4	1	0	19	6	4	29	24	6.1
2	8	6	5	1	3	1	0	0	0	9	9	6	24	17	4.3
3	5	7	1	0	0	0	0	1	0	5	8	1	14	11	3.6
4	8	10	2	0	0	0	0	4	0	8	14	2	24	18	4.5
5	0	14	2	0	2	0	0	0	0	0	16	2	18	11	2.8
6	4	9	2	0	0	0	0	1	0	4	10	2	16	11	3.8
7	1	3	2	0	0	0	0	0	0	1	3	2	6	4	1.8
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
10	2	3	1	0	0	1	0	0	0	2	3	2	7	5	2.3
11	1	10	2	0	1	3	0	1	0	1	12	5	18	11	3.6
12	10	8	3	0	3	0	0	1	0	10	12	3	25	19	6.3
Total	**39**	**70**	**20**	**1**	**9**	**5**	**0**	**8**	**0**	**59**	**93**	**29**	**181**	**131**	**39**
Avg/wk	**3.5**	**6.4**	**1.8**	**0.1**	**0.8**	**0.5**	**0.0**	**0.7**	**0.0**	**4.9**	**7.8**	**2.4**	**15.1**	**14.1**	**4.1**
Avg/d															**1.0**

* Weighted number of procedures were calculated using the formula: Weighted # of procedures = [(3/3 x # large) + (2/3 x # medium) + (1/3 x # small)]

** Weighted number of procedures divided by the number of dentists reporting activity.

Appendix B

QA/QC Summary - Dental Amalgam Project - Filtrates

Filtrate Reagent Blanks

Data Source	Sample ID	Conc (ng/l)	Conc (ng/l)	Mean Conc (ng/l)	Std Dev Mean LOD (ng/l)	LOQ (ng/l)
Dental Filtrate Run #1gtw.xls	reag blk A	19.0	**8.6**	**5.1**	**15.2**	**50.6**
	reag blk B	10.8				
	reag blk C	10.9				
	reag blk D	8.6				
	reag blk E	5.6				
	reag blk F	5.8				
	reag blk G	4.8				
	reag blk H	3.2				
dental filtrate run #2gtwrev.xls	reag blk A	31.6	**23.7**	**3.6**	**10.8**	**36.1**
	reag blk B	23.0				
	reag blk C	25.3				
	reag blk D	24.5				
	reag blk E	21.2				
	reag blk F	22.5				
	reag blk G	20.4				
	reag blk H	21.2				
filtrate run#3gtw.xls	reag blk I	24.0	**12.0**	**6.2**	**18.7**	**62.3**
	reag blk J	19.5				
	reag blk K	14.8				
	reag blk L	8.0				
	reag blk M	7.3				
	reag blk N	7.8				
	reag blk O	8.2				
	reag blk P	12.3				
	reag blk Q	13.9				
	reag blk R	3.9				
filtrate run #4gtw.xls	reag blk I	84.1	**56.4**	**16.7**	**50.1**	**167.0**
	reag blk J	69.8				
	reag blk K	70.1				
	reag blk L	62.5				
	reag blk M	59.8				
	reag blk N	55.8				
	reag blk O	47.6				
	reag blk P	48.4				
	reag blk Q	39.1				
	reag blk R	26.6				
filtrate run#5gtw.xls	reag blk I	32.3				
	reag blk J	21.9	**18.4**	**2.7**	**8.1**	**27.1**
	reag blk K	20.1				
	reag blk L	17.7				
	reag blk M	16.2				
	reag blk N	14.5				
	reag blk O	15.2				
	reag blk P	19.1				
	reag blk Q	21.7				
	reag blk R	19.6				
27Sept2000Bgtw	Reagen Blank A	12.0	**11.5**	**0.3**	**1.0**	**3.3**
	Reagen Blank B	11.0				

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filtrates (cont.)

Carboy Blanks

Data Source	Sample ID	Conc (ng/l)	
Dental Filtrate Run #1gtw.xls	1% brook 1/10-1/11	0.67	
	1% brook 1/24	3.08	
	1% brook 1/31	-0.05	(<LOD)
	1% win 1/24	0.76	
	1% win 1/30'	1.35	
	1% wnew 1/10-1/11	0.06	(<LOD)
	1% wnew 1/24	0.73	
	1% wnew 1/31	0.12	
	1% wrox 1/10-1/11	-0.02	(<LOD)
	1% wrox 1/24	1.35	
	1% wrox 1/31	2.43	
filtrate run#3gtw.xls	1% win wk4	0.64	
	1% wnew wk4	1.04	
	1% brook wk4	-0.05	<LOD
	1% wrox wk4	6.92	
	1%win 3/1/02	16.12	
	1% brook 3/1/02	17.40	
	0.1% win 3/1/02	17.95	
	0.1% brook 3/1/02	8.62	

Filter Blanks

Data Source	Sample ID	Conc (ug/l)		Conc (ug/l)	Conc (ug/l)	Mean %RSD	Std Dev Mean LOD (ug/l)	LOQ (ug/l)
Dental Filtrate Run #1gtw.xls	FB wrox wk6 1/29	0.72		**0.54**	**0.37**	**68%**	**1.1**	**3.7**
	FB win wk6 1/29	1.06						
	FB win wk7 2/5	0.58						
	FB wnew wk7 2/5	0.05						
	FB brook wk8 2/11	0.77						
	FB wrox wk8 2/11	0.27						
	FB wnew wk9 2/20	0.07						
	FB wrox wk9 2/19	0.82						
filtrate run#3gtw.xls	FB win 1/22	14.69	**x**	**0.40**	**0.43**	**110%**	**1.3**	**4.3**
	FB brook 1/22	0.30						
	FB win wk10	0.51						
	FB brook wk10	0.32						
	FB wnew wk11	0.02	<LOD					
	FB brook late wk11	4.75	**x**					
	FB wnew wk12	0.03	<LOD					
	FB brook wk12	1.20						
27Sept2000Bgtw	Filter App Blk 7/19 (filter)	0.40		**0.83**	**0.61**	**74%**		
	Filter App Blk 9/10 (filter)	1.26						

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filtrates (cont.)

Analytical Replicates

	Sample ID	Conc (ng/l)	Mean Conc (ng/l)	Mean Conc (ng/l)	%RSD
Dental Filtrate Run #1gtw.xls	1%brook 1/31	0.05	0.066	0.016	23.6
	1% brook 1/31 REP	0.08			
	FB wnew wk9 2/20	0.07	0.061	0.010	16.8
	FB wnew wk9 2/20 REP	0.05			
	ciampa blk C(2) wk7 2/5'	38.90	38.321	0.822	2.1
	ciampa blk C(2) wk7 2/5' REP	37.74			
	brook wk2 B2'	1002.42	1003.262	1.186	0.1
	brook wk2 B2' REP	1004.10			
	brook wk8 late B'	673.50	693.944	28.914	4.2
	brook wk8 late B' REP	714.39			
	wrox wk3 C'	33.88	34.785	1.279	3.7
	wrox wk3 C' REP	35.69			
	wrox wk8 C'	19.66	19.519	0.200	1.0
	wrox wk8 C' REP	19.38			
	wnew wk3 B'	171.20	166.976	5.981	3.6
	wnew wk3 B' REP	162.75			
dental filtrate run #2gtwrev.xls	dilution blk	0.025	0.023	0.002	8.0
	dilution blk REP	0.022			
	brook wk3 M/T B"	999.1	992.5	9.4	0.9
	brook wk3 M/T B" REP	985.9			
	brook wk7 A"	1219.0	1220.9	2.7	0.2
	brook wk7 A" REP	1222.8			
	wrox wk2 B1"	971.9	975.0	4.4	0.5
	wrox wk2 B1" REP	978.1			
	wrox wk4 C	6.2	6.2	0.0	0.2
	wrox wk4 C REP	6.2			
filtrate run#3gtw.xls	reag blk Q	14.1	13.9	0.3	1.8
	reag blk Q REP	13.7			
	1% wnew wk4	104.1	103.1	1.3	1.2
	1%wnew wk4 REP	102.2			
	FB wnew wk11	11.6	13.6	2.9	21.1
	FB wnew wk11 REP	15.7			
	wrox wk6-C	692.7	691.0	2.5	0.4
	wrox wk6-C REP	689.3			
	wrox wk10-A	692.3	692.2	0.2	0.0
	wrox wk10-A REP	692.1			
	wrox wk12-B(2)	328.9	327.7	1.7	0.5
	wrox wk12-B(2) REP	326.5			
	win wk7-B'	5.72E+03	5.84E+03	171.2	2.9
	win wk7-B' REP	5.96E+03			
	win wk10-B'	3.39E+03	3.37E+03	26.5	0.8
	win wk10-B' REP	3.35E+03			
	wnew wk5-A'	5.38E+04	5.43E+04	613.3	1.1
	wnew wk5-A' REP	5.47E+04			
	wnew wk7-C(2)'	5.28E+04	5.37E+04	1259.7	2.3
	wnew wk7-C(2)' REP	5.46E+04			
	wnew wk10-B'	4.67E+04	4.71E+04	661.9	1.4
	wnew wk10-B' REP	4.76E+04			
	0.1% brook 3/1/02	652.3	648.3	5.5	0.9
	0.1% brook 3/1/02 REP	644.4			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filtrates (cont.)

filtrate run #4gtw.xls	wrox wk7-B'	713.9	699.5	20.3	2.9
	wrox wk7-B' REP	685.2			
	wnew wk6-A"	271.1	275.5	6.3	2.3
	wnew wk6-A" REP	280.0			
	wnew wk8-C"	205.1	202.9	3.2	1.6
	wnew wk8-C" REP	200.6			
	wnew wk12-C"	327.1	337.1	14.1	4.2
	wnew wk12-C" REP	347.1			
	brook wk10-A"	1297.5	1282.0	21.9	1.7
	brook wk10-A" REP	1266.5			
	wnew wk12-C'	297.6	333.9	51.4	15.4
	wnew wk12-C' REP	370.3			
filtrate run#5gtw.xls	wrox wk5-B	13.07	13.2	0.1	0.9
	wrox wk5-B REP	13.24			
	wrox wk9-A(2)	8.47	8.4	0.1	0.7
	wrox wk9-A(2) REP	8.38			
	wrox wk11-B	5.64	5.6	0.02	0.3
	wrox wk11-B REP	5.66			
	win wk5-C"	1207.00	1176.6	43.1	3.7
	win wk5-C" REP	1146.11			
	win wk9-A	37.27	37.5	0.3	0.8
	win wk9-A REP	37.70			
	win wk12-A'	156.74	155.8	1.4	0.9
	win wk12-A' REP	154.77			
	wnew wk6-B"	364.06	363.0	1.5	0.4
	wnew wk6-B" REP	361.92			
	wnew wk9-A"	392.67	393.8	1.5	0.4
	wnew wk9-A" REP	394.86			
	wnew wk11-C(2)'	301.79	302.4	0.8	0.3
	wnew wk11-C(2)' REP	302.92			
	brook wk9 early-A"	2.46E+03	2.46E+03	3.0	0.1
	brook wk9 early-A" REP	2.45E+03			
	brook wk11 late C"	1.97E+03	1.99E+03	26.9	1.4
	brook wk11 late C" REP	2.01E+03			

Procedural Replicates

	Sample ID	Conc (ug/l)	Mean Conc (ug/l)	Std Dev Mean Conc (ug/l)	%RSD
Dental Filtrate Run #1gtw.xls	FB wnew wk9 2/20	0.07	0.1	0.0	33.5
	FB wnew(2) wk9 2/20	0.10			
	win blk C wk7 2/5'	38.94	38.6	0.4	1.1
	win blk C(2) wk7 2/5'	38.32			
	win wk7 A'	34.30	35.4	1.5	4.4
	win wk7 A(2)'	36.49			
	brook wk3 M/T B'	1038.91	1034.6	6.1	0.6
	brook wk3 M/T B(2)'	1030.24			
	wrox wk4 B'	10.21	10.0	0.4	3.6
	wrox wk4 B(2)'	9.71			
	wnew wk2 B1'	257.70	288.4	43.4	15.1
	wnew wk2 B1(2)'	319.12			
	wnew wk4 C'	175.83	176.3	0.7	0.4
	wnew wk4 C(2)'	176.78			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filtrates (cont.)

dental filtrate run #2gtwrev.xls	brook wk3 M/T B"	999.15	1005.5	18.4	1.8
	brook wk3 M/T B(2)"	1018.56			
	wrox wk4 B	4.90	5.1	0.2	4.5
	wrox wk4 B(2)	5.22			
	wrox wk8 A	3.88	3.1	1.1	36.6
	wrox wk8 A(2)	2.29			
filtrate run#3gtw.xls	wrox wk6-C	8.92	8.1	1.1	13.5
	wrox wk6-C(2)	7.37			
	wrox wk9-A	6.25	6.2	0.1	1.2
	wrox wk9-A(2)	6.14			
	wrox wk9-C	6.03	6.8	1.2	16.8
	wrox wk9-C(2)	7.66			
	wrox wk10-A	8.53	8.9	0.5	5.3
	wrox wk10-A(2)	9.20			
	wrox wk12-B	4.17	4.1	0.1	2.4
	wrox wk12-B(2)	4.03			
	win wk12-A'	127.78	129.1	1.8	1.4
	win wk12-A(2)'	130.34			
	wnew wk5-A'	643.67	643.5	0.2	0.0
	wnew wk5-A(2)'	643.35			
	wnew wk7-C'	682.57	706.6	33.9	4.8
	wnew wk7-C(2)'	730.57			
	wnew wk8-A'	391.69	401.4	13.7	3.4
	wnew wk8-A(2)'	411.02			
	wnew wk11-C'	223.37	237.6	20.1	8.5
	wnew wk11-C(2)'	251.81			
	1%win 3/1/02	15.96	17.0	1.4	8.3
	0.1% win 3/1/02	17.95			
filtrate run #4gtw.xls	wnew wk5-A"	572.3	535.6	51.9	9.7
	wnew wk5-A(2)"	499.0			
	wnew wk7-C"	531.0	532.7	2.5	0.5
	wnew wk7-C(2)"	534.5			
	wnew wk8-A"	284.1	274.0	14.3	5.2
	wnew wk8-A(2)"	263.8			
filtrate run#5gtw.xls	wrox wk6-C	12.45	11.4	1.5	13.4
	wrox wk6-C(2)	10.30			
	wrox wk9-A	8.54	8.5	0.1	1.0
	wrox wk9-A(2)	8.42			
	wrox wk9-C	8.46	9.5	1.5	16.0
	wrox wk9-C(2)	10.62			
	wrox wk10-A	11.66	12.1	0.7	5.5
	wrox wk10-A(2)	12.59			
	wrox wk12-B	6.09	6.1	0.1	1.0
	wrox wk12-B(2)	6.01			
	win wk12-A'	155.75	161.0	7.4	4.6
	win wk12-A(2)'	166.15			
	wnew wk5-A"	731.25	705.2	36.8	5.2
	wnew wk5-A(2)"	679.23			
	wnew wk7-C"	714.51	709.4	7.2	1.0
	wnew wk7-C(2)"	704.37			
	wnew wk8-A"	374.55	371.2	4.8	1.3
	wnew wk8-A(2)"	367.77			
	wnew wk11-C'	315.40	308.9	9.2	3.0
	wnew wk11-C(2)'	302.35			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filtrates (cont.)

27Sept2000Bgtw	Wk 1 FA	374.5	380.1	4.9	1.3
	Wk 1 FB	382.5			
	Wk1 FC	383.5			
	WkB FA	478.7	457.8	18.2	4.0
	Wk B FB	445.5			
	Wk B FC	449.2			
	Wk C FA	484.1	478.9	5.8	1.2
	Wk C FB	480.0			
	Wk C FC	472.6			
	Wk D FA	523.9	531.9	6.8	1.3
	Wk D FA R1	544.3			
	Wk D FB	528.6			
	Wk D FC	520.6			
	Wk E FA	690.7	688.6	5.9	0.9
	Wk E FB	693.1			
	WkE FC	681.9			
	Wk E FC R1	682.3			
	Wk F FA	517.9	547.2	40.7	7.4
	Wk F FB	530.1			
	Wk F FC	593.6			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filters

Acid Digestion Reagent Blks

	Sample_ID	Conc (ng/l)		Conc (ug/l)	Mean Conc (ug/l)	Std Dev Mean %RSD
filter run #2gtw.xls	blk'	2375.9		**2.15**	**2.12**	**98%**
	blk 2/11/02 (14)	982.9				
	blk 2/11/02 (m4)	718.1				
	blk 2/13/02	462.4				
	blk 2/13/02 (19)	237.1				
	blk 2/15/02	1126.3				
	blk 2/15/01 (10)	506.1				
	blk 2/7/02'	4198.3				
	blk 3/15/02'	6178.7				
	blk 3/15/02' REP	6174.5				
	blk 3/18/02	29.4				
	blk 3/19/02	117.7				
	blk vial 14	49.4				
	blk vial 18'	5075.2				
	blk vial 6	1080.7				
	blk vial m4'	3765.1				
	blk (1) 3/14/02	1916.5				
	blk (2) 3/14/02"	4.22E+04	**X**			
	blk 1 2/25/02'	3954.6				
	blk 1 2/25/02' REP	3856.9				
	blk 2 2/25/02	285.3				
filter run #3gtw.xls	blank	136.5		**0.11**	**0.04**	**37%**
	blank 3/18/02	109.6				
	blank A	156.3				
	blank B	127.4				
	blank C	34.2				
	blank D	121.9				
	blank E	79.7				

Filter Blanks

	Sample_ID	Conc (ng/l)	Conc (ug/l)	Mean Conc (ug/l)	Std Dev Mean %RSD
filter run #2gtw.xls	FB brook wk5"	2.11E+04	**0.73**	**1.01**	**138%**
	FB win wk5'	1.19E+04			
	FB win wk5' REP	1.20E+04			
	FB win wk6'	2.16E+03			
	FB win wk7'	3.78E+03			
	FB wnew wk7	130.7			
	FB wrox wk6	428.8			
filtrate run#5gtw.xls	FB brook late wk11 filter	240.9			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filters (cont.)

filter run #3gtw.xls	FB win wk10	408.9
	FB wrox wk8	464.0
	FB wrox wk8 REP	461.5
	FB wrox wk9	536.9
	FB wnew wk9	286.6
	FB wnew wk12	209.1
	FB brook wk8	458.1
	FB brook wk10	360.9
	FB brook early wk12	312.7

Analytical Replicates

		Conc (ug/l)	**Mean Conc (ug/l)**	**Mean Conc (ug/l)**	**%RSD**
filtrate run#5gtw.xls	win wk4 filter C!'	1.57E+04	1.55E+04	221.2	1.42
	win wk4 filter C!' REP	1.54E+04			
	wrox wk5 filter A!	1875	1873.1	2.8	0.05
	wrox wk5 filter A! REP	1871			
filter run #2gtw.xls	blk 3/15/02'	6.2	6.2	0.0	2.10
	blk 3/15/02' REP	6.2			
	blk 1 2/25/02'	4.0	3.9	0.1	2.58
	blk 1 2/25/02' REP	3.9			
	FB win wk5'	11.9	12.0	0.1	0.98
	FB win wk5' REP	12.0			
	win wk4-A!"	2.24E+04	2.24E+04	26.5	0.04
	win wk4-A!" REP	2.25E+04			
	wnew wk2-A1"	80	81.1	1.7	2.91
	wnew wk2-A1" REP	82			
	wnew wk5-A1"	154	153.6	0.2	1.74
	wnew wk5-A1" REP	153			
	wnew wk6 filterA"	152	149.1	3.8	0.38
	wnew wk6 filterA" REP	146			
	wrox wk2-C!	2.98E+03	2.98E+03	0.9	12.39
	wrox wk2-C! REP	2.98E+03			
	wrox wk7-A!	2.57E+03	2.59E+03	25.4	0.98
	wrox wk7-A! REP	2.60E+03			
	brook wk3 Fri-B1"	279	278.6	1.1	0.39
	brook wk3 Fri-B1" REP	278			
	brook wk4-A1"	69	68.9	0.0	0.04
	brook wk4-A1" REP	69			
	win wk11-B!	1376	1381.9	8.5	0.61
	win wk11-B! REP	1388			
	brook wk10-A"	35	35.9	1.0	2.91
	brook wk10-A" REP	37			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filters (cont.)

filter run #3gtw.xls	win wk7-B"	103.1	104.5	2.0	1.95
	win wk7-B" REP	105.9			
	win wk12-A"	403.4	398.5	6.9	1.74
	win wk12-A" REP	393.6			
	wrox wk10-A"	279.5	281.4	2.7	0.96
	wrox wk10-A" REP	283.3			
	wnew wk8-B"	172.5	173.0	0.7	0.38
	wnew wk8-B" REP	173.4			
	brook early wk8-A'	46.1	46.6	0.8	1.71
	brook early wk8-A' REP	47.2			
	brook early wk12-B"	110.6	101.7	12.6	12.39
	brook early wk12-B" REP	92.8			
27Sept2000Bgtw	Blank C^	3.02E+04	3.06E+04	570.1	1.9
	Blank C^ REP	3.10E+04			
	Wk ! FB'	2.74E+04	2.76E+04	314.8	1.1
	Wk ! FB' REP	2.78E+04			
	Wk D FA'R1	3.70E+04	3.70E+04	52.3	0.1
	Wk D FA'1 REP	3.71E+04			
	Wk F FC'	4.39E+04	4.41E+04	197.1	0.4
	Wk F FC' REP	4.42E+04			
	WN wkC fB*	6.99E+03	6.96E+03	40.1	0.6
	WN wkC fB* REP	6.93E+03			
Dec_17_02Bgtw	Blank C'	1.32E+05	1.32E+05	1109	0.84
	Blank C' REP	1.31E+05			
	WN wkC fA!	6777	6697	112	1.67
	WN wkC fA! REP	6618			
	WN wkF fB'	4.67E+04	4.65E+04	267	0.57
	WN wkF fB' REP	4.63E+04			

Procedural Replicates

		Conc (ug/l)	Mean Conc (ug/l)	Std Dev Mean Conc (ug/l)	%RSD
filtrate run#5gtw.xls	win blk wk4 filter C1!'	6657	5916	1048	18
	win blk wk4 filter C2!'	5175			
	wnew wk2 filter A1'	77.5	54	33	62
	wnew wk2 filter A2'	30.2			
	wnew wk2 filter B1'	53.5	106	75	70
	wnew wk2 filter B2'	159.0			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Filters (cont.)

filter run #2gtw.xls	wnew wk2-A1"	80	57	34	58
	wnew wk2-A2"	34			
	wnew wk2-B1"	55	119	90	76
	wnew wk2-B2"	183			
	wnew wk2-C1"	202	168	48	28
	wnew wk2-C2"	134			
	wnew wk5-A1"	154	124	42	34
	wnew wk5-A2"	94			
	wnew wk6-A"	174	161	17	11
	wnew wk6 filterA"	149			
	brook wk2-A1!	1212	955	362	38
	brook wk2-A2"	699			
	brook wk3 Fri-B1"	279	201	76	38
	brook wk3 Fri-B2"	198			
	brook wk3 Fri-B3"	127			
	brook wk3 Fri C1"	101	98	4	4
	brook wk3 Fri-C2"	98			
	brook wk3 Fri-C3"	94			
	brook wk4-A1"	69	95	37	39
	brook wk4-A2"	122			
filter run #3gtw.xls	wnew wk5-B1"	366	269	138	51
	wnew wk5-B2"	171			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Solids

Acid Digestion Reagent Blks

	Sample_ID	Conc (ng/l)	Mean Conc (ug/l)	Std Dev Mean Conc (ug/l)	%RSD
hg solids july 19 2002Bgtw_c	blank A 6/29/02	1103	1.65	1.32	80
	blank B 6/21/02 .5	3156			
	blank A 7/8/02	703			
	blank A 7/8/02 REP	703			
	blank new1	317	1.34	1.66	124
	blank new2	605			
	blank new3.5	4660			
	blank new4	1011			
	blank new5	1038			
	control new6	385			
hg solids aug 1 2002Bgtw	7/19/02 Run	787	0.792	0.008	1.0
	7/25/02 Run	798			
27Sept2000Bgtw	Blank A	1370	2.86	3.34	116.8
	Blank B	524			
	Blank C^	30619			
	Blank D^	6686			
Feb5_2003bgtw	Blank E	270	645	367	56.9
	Blank F	662			
	Blank G	1003			

Analytical Replicates

	Sample_ID	Conc (ng/l)	Mean Conc (ug/l)	Std Dev Mean Conc (ug/l)	%RSD
hg solids july 19 2002Bgtw_c	blankA 7/8/02	703	703.1	0.3	0.04
	blankA 7/8/02 REP	703			
	wrox wk3(B)'.5	1.20E+07	1.19E+07	1.31E+05	1.10
	wrox wk3(B)'.5 REP	1.18E+07			
	wnew(I) wk6'	7.48E+05	7.45E+05	4.53E+03	0.61
	wnew(I) wk6' REP	7.42E+05			
	brook wk3 (6/26/02)'	5.33E+06	5.25E+06	1.07E+05	2.03
	brook wk3 (6/26/02)' REP	5.18E+06			
	brook wk8 late TV"	8.98E+04	9.07E+04	1.30E+03	1.43
	brook wk8 late TV" REP	9.17E+04			
	win wk9 (I)'.5	1.77E+07	1.78E+07	1.92E+05	1.08
	win wk9 (I)'.5 REP	1.80E+07			
	amalgam std1'.01	3.74E+08	3.87E+08	1.86E+07	4.80
	amalgam std1'.01 REP	4.00E+08			
	brook fri wk3 (A) (R2)'	2.72E+06	2.70E+06	2.75E+04	1.02
	brook fri wk3(A) (R2)' REP	2.68E+06			
hg solids rerun july 25 2002Bgtw	blank A 7/8/02	682	0.687	0.006	0.87
	blank A 7/8/02 REP	691			
	amalgam std 1 REP 1:100 {1}	4.21E+08	4.17E+05	5218	1.25
	amalgam std 1 REP 1:100 {1} REP	4.13E+08			
hg solids aug 1 2002Bgtw	win wk7 (R2) 0.1	6.20E+07	6.18E+07	2.50E+05	0.41
	win wk7 (R2) 0.1 REP	6.17E+07			
	win wk8 (R2) 0.1	1.28E+08	1.28E+08	2.51E+05	0.20
	win wk8 (R2) 0.1 REP	1.28E+08			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Solids (cont.)

Dec_20_2002Bgtw	Blank C'	1.35E+05	134	1.49	1.11
	Blank C' REP	1.33E+05			
	Amal Std #4 R1 !!	3.69E+08	3.70E+05	2.62E+03	0.71
	Amal Std #4 R1 !! REP	3.72E+08			
Feb5_2003bgtw	Blank G	997	1003	8	0.82
	Blank G Rep	1009			
	Solmetex C ^	2.00E+08	1.99E+08	1.24E+06	0.62
	Solmetex C ^ Rep	1.99E+08			
	Amal Std F	4.65E+08	4.66E+08	1.37E+06	0.29
	Amal Std F Rep	4.67E+08			

Procedural Replicates

	Sample_ID	Conc (g/g solid)	Mean Conc (g/g solid)	Std Dev Mean Conc (g/g solid)	%RSD
hg solids rerun july 25 2002Bgtw	amalgam std 1 1:100 {1}	0.460	0.446	0.019	4.3
	amalgam std 2 1:100 {2}	0.433			
hg solids aug 1 2002Bgtw	win wk7	44.00	71.92	24.27	33.7
	win wk7 (R1)	83.82			
	win wk7 (R2)	87.95			
	brook Fri wk3 A	5.53	4.45	0.93	21.0
	brook Fri wk3 A (R1)	3.92			
	brook Fri wk3 A (R2)	3.90			
	win wk8	90.27	89.09	2.19	2.5
	win wk8 (R1)	86.56			
	win wk8 (R2)	90.43			
	brook wk5 2	1.51	1.49	0.06	4.0
	brook wk5 (R1) 5	1.53			
	brook wk5 (R2) 10	1.42			
27Sept2000Bgtw	Win wk4 R1	0.124	0.127	0.004	3.2
	Win wk4 R2	0.130			
	Win wk5(I)	0.067	0.076	0.007	9.5
	Win wk5(I) R1	0.079			
	Win wk5(I) R2	0.080			
Dec_17_02Bgtw	Win wk 4	0.133	0.135	0.005	3.9
	Win wk 4 R1	0.131			
	Win wk 4 R2	0.141			
	Win wk 5 (1)	0.069	0.081	0.011	14.0
	Win wk 5 (1) R1	0.082			
	Win wk 5 (1) R2	0.092			
	Win wk 5 (2)	0.218	0.241	0.061	25.2
	Win wk 5 (2) R1	0.310			
	Win wk 5 (2) R2	0.196			
	Amalgam Std #4	0.238	0.302	0.091	29.9
	Amalgam Std #5	0.367			
Dec_20_2002Bgtw	Amal Std #1	0.416	0.419	0.004	1.0
	Amal Std #1 R1	0.422			
	Amal Std #2	0.426	0.425	0.003	0.6
	Amal Std #2 R1	0.423			
	Amal Std #3	0.423	0.418	0.007	1.8
	Amal Std #3 R1	0.413			
	Amal Std #4	0.254	0.256	0.002	0.8
	Amal Std #4 R1	0.258			

Appendix B (cont.)

QA/QC Summary - Dental Amalgam Project - Solids (cont.)

Feb5_2003bgtw	Rebec A	0.029	0.028	0.005	19.4
	Rebec B	0.022			
	Rebec C	0.033			
	Metasys A	0.149	0.148	0.003	1.7
	Metasys B	0.145			
	Metasys C	0.150			
	Solmetex A	0.193	0.194	0.005	2.7
	Solmetex B	0.189			
	Solmetex C	0.200			
	W Rox Waste A	0.174	0.173	0.001	0.8
	W Rox Waste A(r)	0.172			
	W Rox Waste B	0.325	0.293	0.046	15.7
	W Rox Waste B(r)	0.260			
	W Rox Waste C	0.062	0.063	0.002	2.6
	W Rox Waste C(r)	0.064			
	W Rox Waste D	0.053	0.056	0.005	8.6
	W Rox Waste D(r)	0.059			
	Amal Std F	0.419	0.392	0.023	6.0
	Amal Std G	0.398			
	Amal Std H	0.363			
	Amal Std I	0.389			

Appendix B (cont.)

QA/QC Sumary - Dental Amalgam Project - Reference Standard

Recovery from Reference Amalgam Material **Hg Concentration = 410 - 420 mg/g**

Run	Concentration (mg/g)	Wt digested (g)
hg solids july 19_2002Bgtw	411.2	0.0942
hg solids july 19_2002Bgtw	414.7	0.0507
hg solids july 19_2002Bgtw	418.0	0.0265
Dec_20_2002Bgtw	256.0	0.1438
Dec_20_2002Bgtw	393.7	0.0934
Feb5_2003Bgtw	419.2	0.1112
Feb5_2003Bgtw	398.0	0.1308
Feb5_2003Bgtw	362.5	0.1023
Feb5_2003Bgtw	389.1	0.1179

		Recovery @410	Recovery @420	Mean	n
Mean	384.7	93.8%	91.6%	92.7%	9
StdDev	51.5	12.6%	12.3%	12.4%	
Alt Mean	400.8	97.8%	95.4%	96.6%	8
Std Dev	19.3	4.7%	4.6%	4.6%	

Appendix B (cont.)

Summary Statistics

Analytical Replicates

	Filtrates	Std Dev	Filters	Std Dev	Solids	Std Dev	Overall	Std Dev
% RSD	3.27	5.55	1.93	3.02	1.23	1.12	2.41	4.25
N	42		29		19		90	

Sample Replicates

	Filtrates	Std Dev	Filters	Std Dev	Solids	Std Dev
% RSD	6.3	8.1	25.5	23.4	8.9	10.0
N	40		N = 53		24	

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