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Environmental Technology Verification Report

Removal of Mercury from Dental Office Wastewater

Dental Recycling North America (DRNA) Mercury Recovery Unit (MRU)

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**SEDIMENTATION AND ADSORPTION OF MERCURY AMALGAM AND MERCURY COMPOUNDS**	
APPLICATION:	**REMOVAL OF MERCURY AMALGAM PARTICULATE AND SOLUBLE AND INSOLUBLE MERCURY FROM DENTAL OFFICE WASTEWATER**	
TECHNOLOGY NAME:	**DENTAL RECYCLING NORTH AMERICA (DRNA) MERCURY RECOVERY UNIT (MRU)**	
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NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center under EPA's Environmental Technology Verification (ETV) Program. As part of the center's activities in verifying the performance of source water protection (SWP) technologies, NSF recently evaluated the performance of a mercury removal unit used in dental offices for removal of mercury from wastewater. This verification statement provides a summary of the test results for the Dental Recycling North America (DRNA) Mercury Recovery Unit (MRU). The NSF laboratories, in conjunction with Scherger Associates, performed the verification testing.

The Environmental Technology Verification Program was created by EPA to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with testing organizations and stakeholder advisory groups consisting of buyers, vendor organizations, permitters, and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in

accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ABSTRACT

Verification testing of the DRNA Mercury Recovery Unit (MRU) was conducted during a seven-week period, at a dental office in Michigan that had three operatory rooms and two hygiene rooms. The office operated four days per week and averaged approximately eight (8) mercury amalgam surfaces removed/placed per day. The MRU was installed in the vacuum system ahead of the air/water separator, and operated continuously over the verification test period. During an eleven-week period prior to the verification test period, a baseline characterization test was conducted with the total volume of untreated wastewater generated at the office being sampled and analyzed. The characterization data provided representative influent data for comparison with the treated water effluent data collected during the verification test. Mercury removal was calculated by two methods. One approach used the data collected during the characterization test to represent the influent wastewater quality. The second approach used a mass balance that measured all of the mercury captured and discharged by the MRU during the verification test. The MRU achieved mercury removal, on a total mass-loading basis, of 98.3 to 99.4 percent depending on the approach used. The removal of settleable mercury, which represented 77 to 81 percent of the mercury in the wastewater, averaged 99.6 to 99.9 percent. Mercury present in the liquid fraction after settling (soluble and suspended particulate) was removed by the adsorption media in the 92.3 to 94.0 percent range. Both settleable mercury and mercury present in the liquid after settling (soluble and suspended particulate) were effectively removed from the wastewater. The system operated throughout the verification test with no maintenance or down time. There was evidence that the activated carbon adsorption media was breaking down and exiting the unit during the verification test. DRNA indicated this was due to excess bleach being fed to the unit. The concentration of the bleach solution was subsequently decreased during the verification test, and reflects the recommended bleach concentration in the Operations and Maintenance Manual currently being supplied with their units.

TECHNOLOGY DESCRIPTION

The DRNA Mercury Recovery Unit is designed to remove mercury from dental wastewater using a two-step process to address both the insoluble and soluble mercury present in wastewater. Soluble mercury is defined as the mercury, whether in solution or fine particulate, that can pass through a 0.45 micron filter. The verification testing was performed using a full scale, commercially available MRU. The test unit was received as a self-contained system that included all of the parts needed for installation. The equipment included the BullfroHg™ Air/Water/Amalgam Separator, an adsorbent column with particle filter, pump timers, twin peristaltic pumps with waste sensor, and a 10-liter bleach reservoir. The unit came with all of the tubing and fittings to connect the unit to the dental office vacuum system.

The BullfroHg unit is designed to remove mercury amalgam particles from dental wastewater by gravity settling. It is a combined solid and air/water separator that is installed on the suction side of a dental vacuum pump. Three-phase flow (air/water/solids) enters the BullfroHg, where the entrained solids and liquids are retained within the unit and the air flows out to the system vacuum pump. Particles are allowed to settle for several hours after the vacuum system is shut down at the end of the operating day. At the conclusion of settling, a timer-activated pump transfers wastewater from the settling chamber to the adsorbent column, where it passes through adsorbents and a fine particle filter. Amalgam particles remain trapped within the gravity separator unit, while soluble mercury and mercury associated with suspended fine particles are adsorbed onto the column media. A particle filter is located at the end of the column to capture fine particulate not adsorbed by the column media. The treated wastewater is discharged to the sewer system. Approximately 200 mL of bleach solution is pumped into the adsorbent column each day to control biological growth within the column. Mercury captured within the MRU is

typically returned to DRNA for recycle. DRNA has arrangements with mercury recovery companies to recycle the mercury trapped or adsorbed by the MRU, as well as from the chair side traps that are part of a typical vacuum system. The mercury recovery/recycling process used by DRNA was not part of this verification process.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test was performed at a dental office in Southeast Michigan. This general dentistry practice was representative of a small dental office with one or two dentists. The office had five chairs, with two chairs being used for dental hygiene work and three chairs for general dentistry procedures, and typically operated four days per week. During the initial characterization period, there was one dentist in the office. During the verification test period, a second dentist was added on a part time basis. The office uses a dry vacuum system.

Methods and Procedures

During both the wastewater characterization and verification test periods, the entire wastewater flow from the vacuum collection system was collected each day the dental office was open, and was sent to the NSF laboratory by courier service in iced coolers. The samples were prepared in the laboratory and analyzed for total mercury in the settleable solids, total mercury in the decant liquid from the settling procedure and soluble mercury in the decanted liquid. The daily wastewater volume, mass of settleable solids, and pH were also determined. A special procedure was used to separate the settleable solids in the wastewater. The entire sample was placed in a large settling chamber and solids were allowed to settle for at least eight (8) hours. After settling, the liquid fraction containing suspended particles was removed from the settling chamber. The settled solids were collected, filtered, weighed and analyzed for total mercury. The liquid fraction was split into two samples. One sample was analyzed for total mercury, the other sample was filtered through a 0.45 micron filter, and the filtrate analyzed to determine soluble mercury. At the end of the verification test period, residue samples were obtained by removing the solids from the BullfroHg separator, and by removing the adsorbents and particle filter from the adsorbent column. These residues were analyzed for total mercury in order to complete a mass balance of mercury in the MRU.

All samples were preserved and analyzed in accordance with EPA approved methods. Mercury was determined using EPA Method 245.1 for liquids and 245.5 for solids, and Method 150.1 was used for pH determinations.

PERFORMANCE VERIFICATION

System Operation

The MRU was installed in accordance with the manufacturer's instructions received with the unit. The total time to install the unit was less than three hours. The system was wet tested for leaks and to verify the pumps were working properly. After this initial check, the unit operated with no mechanical changes or maintenance for the duration of the seven-week verification test period.

The bleach solution was initially made at the recommended concentration of one part bleach to one part water. After approximately three weeks of operation, the effluent from the MRU was very black in color, and the mercury levels in the effluent increased from less than 1 µg/L to between 1 and10 µg/L. According to DRNA, it was likely that the bleach solution was too strong and was causing a breakdown of the activated carbon, resulting in carbon fines passing through the particle filter and exiting in the effluent. During the characterization phase of the technology verification, DRNA revised their O&M Manual to recommend one part bleach to two parts water. However, this information was not provided

until NSF contacted DRNA about the change in the MRU effluent quality. The bleach concentration was subsequently changed to the revised recommended concentration of one part bleach to two parts water. Carbon fines continued to be discharged from the MRU at reduced levels after the bleach concentration was reduced. DRNA has since revised the recommended bleach concentration once again to one part bleach to three parts water. However, no testing was performed using this concentration.

Wastewater Characterization Results

The wastewater characterization test was conducted from July 10 through September 21, 2001, with 44 complete sample sets being collected over the eleven-week period. The dental office normally operated four days per week, and samples were collected at the end of each normal business day. Three hundred thirty four (334) mercury amalgam surfaces were removed and/or placed during the characterization test. Each wastewater sample was allowed to settle in the laboratory to separate the settleable solids from the wastewater, resulting in three samples for mercury measurement - total mercury in the settleable solids, total mercury in the liquid fraction (decant after settling, including both suspended particulate matter and soluble mercury), and soluble mercury in the liquid fraction. The wastewater flow (all flow collected as sample) averaged 2.2 liters per day, ranging from a high flow of 5.9 liters per day to a low of 0.13 liters per day.

The average total mercury concentration in the wastewater (settleable solids plus mercury in the decant liquid) was 657 µg/L, varying from a high of 1810 µg/L to a low of 73 µg/L. The average mass of mercury was 1.60 mg/day, varying from 0.05 mg/day to 6.81 mg/day. The decanted liquid fraction (after settling) averaged 192 µg/L. The soluble mercury fraction in the decanted liquid averaged 127 µg/L, and typically represented 50-70 percent of the mercury in this fraction of the wastewater. The summary statistics for the wastewater characterization are presented in Table 1.

Table 1. Mercury Data Summary – Wastewater Characterization Test

	Decant Liquid Concentration (mg/L)		Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble		Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Average	0.192	0.127	2180	1.23	0.364	657	1.60
Maximum	0.676	0.632	5880	6.49	1.90	1810	6.82
Minimum	0.0446	0.0044	129	<0.01	0.0094	72.6	0.0537
Std. Dev	0.152	0.139	1410	1.81	0.369	581	1.94
Total Mass/ vol.			100,000	54.2 (mg)	16.7 (mg)		

Verification Test Results

The verification test was performed from September 24 through November 8, 2001, with 32 complete sample sets of MRU treated effluent being collected and analyzed. During the seven-week verification period, the dental office added a dentist on a part time basis. The office operated on a four or five day per week schedule with 243 mercury amalgam surfaces being removed/placed on 29 operating days. The average amalgam surface removal/placement rate of 8.38 surfaces per operating day was similar to the rate during the characterization test (7.73 – 7.95 surfaces per day).

MRU effluent wastewater samples were handled in the same manner as during the characterization test, resulting in three samples for mercury measurement - total mercury in the settleable solids, total mercury in the liquid fraction (decant after settling, including both suspended particulate and soluble mercury), and

soluble mercury in the liquid fraction. The results of the analyses are presented in Table 2. The average total mercury discharge concentration from the MRU was 10.3 µg/L, with a maximum of 39.8 µg/L and a minimum of <0.2 µg/L. The average mass of mercury discharged on a daily basis was 0.036 mg/day, with the settleable solids portion representing an average of 0.007 mg/day and the liquid fraction having an average of 0.0284 mg/day. The mercury contribution from the settleable solids represented 19 percent of the mercury present in the discharge after treatment versus 77 percent in the untreated wastewater.

Table 2. Summary Statistics Mercury Results for DRNA MRU Effluent

	Decant Liquid Concentration (mg/L)		Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble		Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Average	0.0079	0.0027	2550	0.0073	0.0284	10.3	0.0357
Maximum	0.0337	0.0135	6060	0.043	0.177	39.8	0.217
Minimum	<0.0002	<0.0002	177	0.00	<0.0002	<0.2	<0.0003
Std. Dev	0.0108	0.0037	1770	0.0103	0.0507	12.8	0.0601
Total mass			81,700	0.234 (mg)	0.909 (mg)		

Note: All Values below Detection Limit set equal to zero in calculation

The mercury concentration in the discharge was either below the detection limit (<0.2 µg/L) or in the 0.2 to 3.5 µg/L range for the first eighteen days of the verification test. During the first few days, the effluent had no settleable solids and had very low suspended solids in the liquid fraction. The effluent then began to darken in color and became very black, with noticeable suspended particulate present; however, only a small portion of these solids settled. The amount of solids being filtered from the liquid fraction began to increase and the solids were very black and fine in appearance. The bleach solution was changed to the new recommended strength about 3½weeks into the test, and over the next 1½weeks, the total mercury concentration in the effluent, the mass of settleable solids found in the separation procedure, and the amount of solids being filtered from the decant liquid reached peak levels. For the last two weeks, the mass of dry solids and the mercury concentration in the MRU effluent stabilized and began to decrease. On the last two days of the verification test, the mass of solids and the mercury concentration in the effluent again increased. It was noted that the total flow from the dental office was higher than average on these final two days. The final day's flow was impacted by the extra flushing of the vacuum system performed to clear the lines at the end of the test. On the second to last day of the test, the number of mercury amalgam surfaces removed and placed was higher than average. These factors may have impacted the performance of the MRU.

DRNA MRU Performance

As described in the general protocol for test plan development, it was not possible to collect influent and effluent samples simultaneously during the verification period due to the small volume of the influent flow, the operation of the system under vacuum, and the difficulty of obtaining representative samples (particularly of solids) from small pipes, with small intermittent flow under vacuum. The test plan was designed to obtain data that could be used for two different approaches to determine the treatment efficiency of the unit. The first approach used the characterization test data, collected for the eleven weeks prior to the verification test period, to determine the average mercury concentration and average mercury mass discharged from the dental office on a daily basis. The dental office operation was similar during both the characterization period and the verification period, which allowed the characterization data to be used as a substitute for the actual influent characteristics during the verification test period. For

the second approach, effluent quality was measured directly during the verification test period. At the end of the test period, a mass balance for the MRU was completed using the effluent data collected during the verification test period and the mass of mercury retained in the MRU.

Characterization Data vs. Verification Data

Comparing the characterization data to the treated effluent data shows that the DRNA MRU was effective in removing the settleable solids and the mercury in these solids, achieving better than 99 percent removal either on an average concentration basis or on a total mass basis. As shown in Table 3, the overall removal of mercury (solids and liquid combined) was 98.7 percent on a concentration basis and 98.3 percent on a total mass basis. Removal efficiency for the mercury associated with the settleable solids was 99.6 percent. The MRU also was effective in removing the mercury associated with the decant liquid fraction (soluble and suspended mercury) showing an efficiency of 92.8 percent.

Table 3. Removal Efficiency Based on Characterization Data- Total Mass and Average Concentration

	Settleable Solids Mass (mg)	Decant Liquid Mass (mg)	Total Wastewater	
			Concentration (µg/L)	Mass (mg)
Characterization (7/30-9/20/2002)	53.3	12.7	778	66.0
MRU Discharge (9/25-11/9/2002)	0.234	0.909	10.3	1.14
% Removal	99.6	92.8	98.7	98.3

Mass Balance of Verification Data

The second approach to calculating removal efficiency is based on measuring all of the mercury retained in the unit during the verification test and calculating the total load to the MRU (retained mercury + discharged mercury = total influent mercury). Using this approach, the DRNA MRU removed over 99 percent of the mercury in the settleable solids and over 99 percent of the total mercury delivered to the MRU. The MRU was also effective in reducing the mercury in the liquid fraction by 94 percent. The results for the verification test mass balance are shown in Table 4. The removal efficiencies calculated by the mass balance are similar to the removal efficiencies found using the characterization data. In general, the mass balance approach does tend to show somewhat larger removal efficiencies because there was a greater total mass of mercury, particularly in the settleable solids, during the verification test than during the characterization test.

Under these conditions, verification testing demonstrated the DRNA MRU to be capable of removing greater than 99 percent of the mercury associated with settleable solids, 92 to 94 percent of the mercury associated with the liquid fraction (soluble plus suspended particulate), and 98 to 99 percent of the total mercury present in the wastewater.

Table 4. Removal Efficiency based on Mass Balance of Retained and Discharged Mercury

	Mass of Mercury		
	Settleable Solids (mg)	Decant Liquid (mg)	Total Wastewater (mg)
Separator-Retained	181	-	181
Filter-Retained	-	0.049	0.049
Carbon-Retained	-	4.98	4.98
Resin-Retained	-	9.24	9.24
Discharge	0.234	0.909	1.14
Total Mass Load	182	15.2	197
% Removal	99.9	94.0	99.4

Operation and Maintenance Results

The MRU was easy to operate, requiring no operator intervention except for occasionally verifying pump operation and weekly checks of the bleach solution level. Once the unit was installed and operational, there were no maintenance requirements other than replenishing the bleach solution, and the unit performed without interruption for seven weeks. DRNA's recommended maintenance interval is 6-12 months depending on the amount of material treated in the wastewater stream. Visual observations made during the verification test, and a review of the type of pumps and materials of construction used in the MRU, did not indicate otherwise. The only operational problem encountered during the verification test was the increase in solids in the MRU effluent, apparently from the bleach solution causing the carbon to breakdown and be discharged. The bleach solution to water ratio was adjusted to what DRNA recommends for units currently being sold.

Two quantifiable O&M factors that apply to the DRNA MRU are electrical usage and chemical usage. The electrical power requirement was 120VAC, 4 amps for each of the two pumps in the unit. Total electrical use can be expected to average about 2,400 watts per day. At a mix ratio of 1 part bleach to 3 parts water, approximately 1.2 liters of bleach per month will be used.

The MRU did not require cleanout or maintenance during the verification test period. Observation during the recovery of the settleable solids from the separator showed that less one percent of the solids separator volume (<100 mL of solids in a 10 liter unit) was accumulated during the seven-week test period. The separator should therefore have sufficient capacity to hold six months to one year of solids at the accumulation rate experienced during the verification test. DRNA provided proprietary information on the mercury adsorbing capacity of the adsorbent material. Measurement of the weight of adsorbent in the MRU combined with results of quality control samples that independently measured the adsorption of mercury, indicated sufficient adsorption capacity to treat soluble mercury for six months to one year, assuming no breakdown of the adsorbent material. The costs associated with cleanout of the MRU on the regularly scheduled change out (6 – 12 months) are the cost to ship the unit to DRNA and the cost associated with the recycling service. The MRU has been designed to facilitate the change out for return to DRNA, with quick disconnects and an arrangement that will assure complete containment of the MRU content during shipping.

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NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report in no way constitutes an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Protocol for Verification Testing for Mercury Amalgam Removal Technologies* dated April 2001, the Verification Statement, and the Verification Report are available from the following sources:

Source Water Protection ETV Pilot Manager (order hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140

NSF web site: http://www.nsf.org/etv (electronic copy)

EPA web site: http://www.epa.gov/etv (electronic copy)

(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

September 2002

Environmental Technology Verification Report

Removal of Mercury from Dental Office Wastewater

Dental Recycling North America (DRNA)
Mercury Recovery Unit (MRU)

Prepared for:
NSF International
Ann Arbor, MI 48105

Prepared by
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Under a cooperative agreement with the U.S. Environmental Protection Agency

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Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a Cooperative Agreement. The Source Water Protection Pilot, now part of the Water Quality Protection Center, operating under the Environmental Technology Verification (ETV) Program supported this verification effort. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA) by a testing organization comprised of the NSF laboratory and Scherger Associates in cooperation with Dental Recycling North America, Inc. The test was conducted from July through November 2001 at a dental office in Michigan.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. The Environmental Technology Verification Program was initiated in 1995 by EPA, to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies are made available to end users regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages rapid availability of new and innovative approaches to environmental protection and reduction of human health risks.

The EPA has partnered with NSF, an independent, not-for-profit testing and certification organization, to verify the performance of commercial-ready treatment systems designed to remove pollutants and protect water quality. A goal of verification testing is to enhance and facilitate the acceptance of small treatment systems and equipment by state regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF will meet this goal by working with manufacturers and NSF-qualified Testing Organizations (TO) to conduct verification testing under the approved protocols. NSF's testing laboratory and Scherger Associates is one such TO.

NSF is conducting the Source Water Protection (SWP) Pilot, now part of the Water Quality Protection Center, with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, Edison, New Jersey. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the TO.

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Glossary of Terms

Accuracy - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Commissioning – the installation of the mercury amalgam removal technology (free of mercury residuals) and start-up of the technology using test site wastewater.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a qualitative term that expresses confidence that all necessary data have been included.

Infrastructure and Watershed Protection Stakeholder Advisory Group - a group of individuals, established under the VO, consisting of any or all of the following: buyers and users of mercury amalgam removal and other technologies, developers and vendors, consulting engineers, the finance and export communities, and permit writers and regulators.

Mercury Free Water – laboratory prepared water used in analysis and cleaning procedures that is tested to ensure the mercury concentration in the water is <0.2 µg/L.

Mercury, Filterable – mercury that can be removed from a wastewater sample by settling and filtration through a 0.45 micron filter. Determined by subtracting the soluble mercury from the total mercury in the liquid sample after settling and adding the settleable mercury concentration or mass. Filterable mercury = (Total mercury – soluble mercury) + settleable mercury.

Mercury, Settleable – total mercury measured in the settled residue from the wastewater sample after settling the wastewater for eight to sixteen hours in accordance with the SOP for sampling handling and settling.

Mercury, Soluble – mercury measured in the filtrate from a liquid sample that has been filtered through a 0.45 micron filter.

Mercury, Total – mercury measured in the liquid sample after removal of settleable solids. The sample is allowed to settle for 8-16 hours and the liquid is decanted. The liquid sample is not filtered. The entire sample, including liquid and any remaining particulate present, is used for the analysis.

Owner – the owner of a dental office used as a test site for verification testing.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, scope and procedures for the study. A protocol shall be used for reference during Vendor participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Residuals – the waste streams, excluding final effluent, which are retained by or discharged from the technology.

Glossary of Terms (cont.)

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Surfaces - refers to the surface of a tooth. There are five possible surfaces per tooth, top and four sides.

Technology Panel - a group of individuals established by the VO with expertise and knowledge in mercury amalgam removal technologies.

Testing Organization – an independent organization qualified by the Verification Organization to conduct studies and testing of mercury amalgam removal technologies in accordance with protocols and test plans.

Vendor – a business that assembles or sells mercury amalgam removal equipment.

Verification – to establish evidence on the performance of mercury amalgam removal technologies under specific conditions, following a predetermined study protocol(s) and test plan(s).

Verification Organization – an organization qualified by USEPA to verify environmental technologies and to issue Verification Statements and Verification Reports.

Verification Report – a written document containing all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The Verification Test Plan(s) shall be included as part of this document.

Verification Statement – a document that summarizes the Verification Report and is reviewed and approved by USEPA.

Verification Test Plan – A written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of mercury amalgam removal equipment at a particular test site. At a minimum, the Verification Test Plan includes detailed instructions for sample and data collection, sample handling and preservation, and quality assurance and quality control requirements relevant to the particular dental office test site.

Abbreviations and Acronyms

ANSI	American National Standards Institute
ASQC	American Society for Quality Control
DRNA	Dental Recycling North America, Inc.
DQI	data quality indicators
DQO	data quality objectives
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification
MSDS	material safety data sheets
MRU	Mercury Recovery Unit
NSF	NSF International
NRMRL	National Risk Management Research Laboratory
O&M	Operation and maintenance
ORD	Office of Research and Development, USEPA
OSHA	Occupational Safety and Health Administration
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
QMP	quality management plan
SAG	Stakeholders Advisory Group
SOP	standard operating procedure
SWP	Source Water Protection
SWPP	Source Water Protection Pilot
TCLP	toxicity characteristic leaching procedure
TO	Testing Organization
USEPA	United States Environmental Protection Agency
VO	Verification Organization
VTP	Verification Test Plan

Acknowledgments

The Testing Organization (TO), a coalition comprised of the NSF International laboratory, Scherger Associates, and Mr. Adam Markie, was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

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Mr. Michael Richards, Environmental Chemist at NSF, was invaluable in his coordination of all laboratory analyses, performing the special mercury analysis procedures, and processing of the resulting data. Mr. Steve Williams at NSF handled the incoming sample and processing program and provided hands-on expertise in removing the solid residues from the MRU at the end of the verification test.

Chapter 1 – Introduction

1.0 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of innovative, improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, consulting engineers, and regulators; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory (as appropriate) testing, collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Source Water Protection Pilot (Pilot), one of 12 technology areas under ETV. This Pilot evaluated the performance of the Dental Recycling North America Mercury Recovery Unit (DRNA MRU), which is designed to remove mercury amalgam from wastewater from dental offices. DRNA sells the MRU unit to remove particulate and soluble mercury that is present in the discharge from dental office vacuum systems. The MRU includes a mercury amalgam separator unit based on sedimentation theory for removal of particulate and an adsorbent system that removes soluble mercury by adsorption onto a solid media. This document provides the verification test results for the Dental Recycling North America Mercury Recovery Unit. DRNA recycles the mercury trapped in the MRU when the MRU is returned to them. The mercury recycling process was not part of this verification.

1.1 Testing Participants and Responsibilities

The ETV testing of the DRNA MRU was a cooperative effort between the following participants:

NSF International
Scherger Associates
Mr. Adam Markie
DRNA
USEPA

1.1.1 NSF International – Verification Organization (VO)

The Source Water Protection ETV Pilot is administered through a cooperative agreement between USEPA and NSF International (NSF). NSF is the verification partner organization for the Source Water Protection Technologies Pilot (SWPP). NSF administers the Pilot, and organized the Testing Organization to develop and implement the Verification Test Plan (VTP).

NSF's responsibilities as the Verification Organization include:

- Reviewing and commenting on the VTP;
- Coordinating with peer-reviewers to review and comment on the VTP;
- Coordinating with the EPA Pilot Manager and the technology vendor to approve the VTP prior to the initiation of verification testing;
- Reviewing the quality systems of all parties involved with the Testing Organization and subsequently, qualifying the companies making up the Testing Organization;
- Overseeing the technology evaluation and associated laboratory testing;
- Carrying out an on-site audit of test procedures;
- Overseeing the development of a verification report and verification statement;
- Coordinating with EPA to approve the verification report and verification statement; and
- Providing QA/QC review and support for the TO.

Key contacts at NSF for the Verification Organization are:

Mr. Thomas Stevens, Program Manager
(734) 769-5347 email: stevenst@nsf.org

Ms. Maren Roush, Project Coordinator
(734) 827-6821 email: mroush@nsf.org

NSF International
789 N. Dixboro Road
Ann Arbor, Michigan 48105
(734) 769-8010

1.1.2 U.S. Environmental Protection Agency

The USEPA Office of Research and Development through the Urban Watershed Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Source Water Protection pilot activities. The USEPA reviews and approves each phase

of the verification project. The USEPA's responsibilities with respect to verification testing include:

- VTP review and approval;
- Verification Report review and approval; and
- Verification Statement review and approval.

The key USEPA contact for this program is:

Mr. Ray Frederick, Project Officer, ETV Source Water Protection Pilot
(732)-321-6627 email: frederick.ray@epa.gov

U.S. EPA, NRMRL
Water Supply and Water Resources Division
2890 Woodbridge Ave. (MS-104)
Edison, NJ 08837-3679

1.1.3 Testing Organization

The Testing Organization (TO) for the DRNA MRU verification testing was a consortium of the NSF International laboratory, Scherger Associates, and Mr. Adam Markie. This group was organized by NSF to bring together resources that could complete a high quality verification test program in a cost effective manner. Each participant in the consortium had a well-defined role in planning and executing the VTP.

Mr. Dale Scherger of Scherger Associates served as the Project Manager for the TO and was responsible for coordination and development of the VTP, obtaining all of the information needed to plan and execute the VTP, managing the data collected during the test period, preparing the draft final report, and providing technical guidance in conjunction with the Technology Panel. Mr. Adam Markie provided field support at the test site, including setup and operation of the MRU, collection of the daily and weekly records from the dental office, and collection and shipment of the samples on a daily basis. Mr. Markie provided any maintenance support required during the verification test period in consultation with the vendor, DRNA.

NSF International provided the laboratory services for the testing program and provided consultation on and implementation of any sampling and analytical issues addressed during the verification test period. NSF was responsible for all quality assurance for the VTP through its QA group. NSF provided administrative and technical support for review and production of the VTP and the Final Report. NSF also handled project management and cost tracking support for the project. The NSF staff involved in the verification testing process as members of the TO were separate from the NSF management and staff that provided the oversight for the ETV program as members of the VO.

The responsibilities of the TO consortium included:

- Preparation of the VTP;
- Conducting Verification Testing, according to the VTP;
- Installation, operation, and maintenance of the MRU in accordance with the Vendor's O&M manual(s);
- Controlling access to the area where verification testing was carried out;
- Maintaining safe conditions at the test site for the health and safety of all personnel involved with verification testing;
- Scheduling and coordinating all the activities of the verification testing participants, including establishing a communication network and providing logistical and technical support on an "as needed" basis;
- Resolving any quality concerns that were encountered and reporting all findings to the Verification Organization;
- Managing, evaluating, interpreting and reporting on data generated by verification testing;
- Evaluation and reporting on the performance of the technology; and,
- Documenting changes in plans for testing and analysis, and notifying the Verification Organization of any and all such changes before changes were executed.

The key personnel and contacts for the TO are:

Scherger Associates
Mr. Dale Scherger
(704)-947-7050 email: daleres@aol.com

Scherger Associates
3017 Rumsey Drive
Ann Arbor, MI 48105

Adam Markie – Field Support
Mr. Adam Markie
(810) 727-7980 email: None

68661 Stoecker Lane
Richmond, MI 48062

NSF International – Laboratory Support

Mr. Steve Williams,
(734) 769-5357 email: williams@nsf.org

NSF International – Quality Assurance Support

Bruce DeMaine, Manager, QA and Safety
(734) 769-5143 email: demaine@nsf.org

1.1.4 Technology Vendor

The mercury removal technology evaluated was the Mercury Recovery Unit (MRU) manufactured and distributed by Dental Recycling North America, Inc. (DRNA). DRNA was responsible for supplying all of the equipment needed for the test program and supporting the TO in ensuring that the equipment was properly installed and operated during the verification test period. Specific responsibilities of the vendor included:

- Initiating application for ETV testing;
- Providing input regarding the verification testing objectives to be incorporated into the VTP;
- Selecting the test site;
- Providing complete, field-ready equipment and the operations and maintenance (O&M) manual(s) typically provided with the technology (including instructions on installation, start-up, operation and maintenance) for verification testing;
- Providing any existing relevant performance data for the technology;
- Providing assistance to the Testing Organization on the operation and monitoring of the technology during the verification test period, and logistical and technical support as required;
- Reviewing and approving the VTP;
- Reviewing and commenting on the Verification Report and Statement; and
- Providing funding for verification testing.

The key contact for DRNA is:

Mr. Marc Sussman
(212) 956-5188 email: mmsussman@aol.com

Dental Recycling North America, Inc.
145 West 58th Street
New York, NY 10019
www.drna.com

1.1.5 ETV Test Site

The verification test was performed at a general practice dental office in Michigan, which is representative of a small dental office with one or two dentists. The dentist requested that his name and address not be disclosed in the verification report. The dental office typically operated four (4) days per week. The office had five chairs, with two being used for dental hygiene work and three for general dentistry procedures. During the characterization period, there was one dentist in the office using two general dentistry chairs. During the verification test period, a second dentist was added on a part time basis using the third general dentistry chair. The office uses a dry vacuum system. The host test site was responsible for some record keeping and providing information on activities that may have affected the characterization and verification test results. These responsibilities included:

- Providing logistical support and reasonable access to the equipment and facilities for sample collection and equipment maintenance;
- Notifying the Testing Organization of any significant changes in dental practices that could affect the volume and composition of wastewater produced at the site; and,
- Recording the tooth number and number of amalgam surfaces placed and removed, the flushing procedure used (chemicals used, volume and frequency) and when chair side traps or vacuum filters were changed (this system was a dry system so there were no filters).

1.1.6 Technology Panel

Representatives from the Technology Panel assisted the Verification Organization in reviewing and commenting on the VTP. The Panel also provided technical and professional support to the TO during all phases of the verification test period. Panel members reviewed and commented on the Verification Report.

1.1.7 Stakeholder Advisory Group

The Watershed Protection Stakeholder Advisory Group was instrumental in approving the development of the Verification Protocol that served as the basis for the development of the *ETV Protocol for the Verification of Mercury Amalgam Removal Technologies.*

1.2 Sources and Fate of Mercury in the Environment

The following discussion is taken as excerpts from the USEPA website maintained by the agency to inform the public and scientific community on issues related to mercury in the environment. The reader is referred to the EPA website (http://www.epa.gov/mercury/index.html) and to reports by the Science Advisory Board, the USEPA and others for more information. The EPA website provides references on the topic of mercury contamination and discharge to the

environment. The EPA produced a white paper regarding mercury in the environment, which can be found at www.epa.gov/ttn/oarpg/t3/memoranda/whtpaper.pdf.

Mercury is a naturally occurring element that is present throughout the environment. Human activity can release some of that mercury into the air, water and soil. In the U.S., coal-fired power plants are the biggest source of mercury emissions to the air. Mercury concentrations in air are usually low and of little direct concern. However, when mercury enters water, biological processes transform it to a highly toxic form that builds up in fish and animals that eat fish. People are exposed to mercury primarily by eating fish. The Environmental Protection Agency is working to reduce the amount of mercury in the environment.

Most of the mercury entering the environment is the result of air emissions; however, mercury also can directly contaminate land and water as a result of the release of industrial wastewater or from the disposal of waste-containing batteries and other sources of mercury. Once mercury enters waters, either directly or through air deposition, it can bioaccumulate in fish and animal tissue in its most toxic form, methylmercury. Bioaccumulation means that the concentration of mercury in predators at the top of the food web (for example, predatory fish and fish-eating birds and mammals) can be thousands or even millions of times greater than the concentrations of mercury found in the water. More information on the sources, fate, and risks of mercury in the environment can be found in EPA's 1997 Mercury Report to Congress and 1998 Utility Air Toxics Report to Congress.

Health Effects and Exposure

For the general U.S. population, exposure to mercury occurs primarily through eating contaminated fish. Women of childbearing age, and people who regularly and frequently eat highly contaminated fish (or large amounts of moderately contaminated fish), are the most likely to be at risk from mercury exposure. Those groups include subsistence fishermen (people who fish for their food) and some Native American populations. Freshwater fish (caught by recreational or subsistence fishermen) from contaminated waters have been shown to have particularly high levels of methylmercury. Mercury contamination is the most frequent basis for fish advisories. Fish consumption advisories have been issued for thousands of water bodies nationwide, including all of the Great Lakes and their connecting waters, which include more than 52,000 lakes and more than 238,000 miles of rivers. As of July 2000, 40 states and one territory (American Samoa) had issued fish consumption advisories for mercury. Thirteen of those states issued advisories for all water bodies in their state; the remaining 27 states issued advisories for more than 1,900 specific water bodies. High mercury levels also have been found in certain saltwater fish. In March 2000, for example, Florida, Georgia, North Carolina and South Carolina issued a joint fish consumption advisory because of high mercury levels in large king mackerel. Certain species of commercially available saltwater fish, such as shark and swordfish, also have high levels of mercury. The U.S. Food and Drug Administration (FDA) issues consumption advice for commercial marine fish. The FDA plans to re-evaluate its current advice in light of a July 2000 report by the National Academy of Sciences that confirmed EPA's mercury reference dose. A reference dose is the level at which people could be exposed to a toxic (in this case, mercury) without the risk of health problems.

Neurotoxicity is the health effect of greatest concern with mercury exposure. Ingested methylmercury is almost completely absorbed into the blood and distributed to all tissues (including the brain); it also readily passes through the placenta to the fetus and fetal brain. The developing fetus is considered the most sensitive to the effects of mercury; therefore, women of childbearing age are the population of greatest concern. Children born of women exposed to relatively high levels of methylmercury during pregnancy have exhibited a variety of developmental neurological abnormalities, including delayed onset of walking and talking, cerebral palsy, and reduced neurological test scores. Far lower exposures during pregnancy have resulted in delays and deficits in learning abilities in children.

In July 2000, the National Academy of Sciences completed a review of the latest scientific evidence regarding the health effects of methylmercury. The Academy confirmed EPA's assessment of the health risks related to mercury exposure and noted that children exposed to mercury in the womb as a result of their mothers' diets during pregnancy may be at special risk of neurological problems. In addition, children exposed after birth are also potentially more sensitive to the toxic effects of methylmercury than adults, because their nervous systems are still developing. Mercury also poses risks to fish-eating wildlife, including some birds and mammals, such as the mink and otter.

Recent Actions to Reduce Mercury Pollution

EPA has taken a number of actions to reduce mercury pollution, including issuing stringent regulations for industries that significantly contribute to mercury pollution. Once fully implemented, these actions will reduce U.S. mercury emissions caused by human activities by nearly 50 percent from 1990 levels. In addition, U.S. industrial demand for mercury dropped 75 percent from 1988 to 1997. The drop can be attributed to a number of actions, including:

- Federal bans on mercury additives in paint and pesticides;
- Industry efforts to reduce mercury in batteries;
- Increasing state regulation of mercury emissions and mercury in products;
- State-mandated recycling programs; and
- Voluntary actions by industry.

EPA also provides technical assistance to state and local governments to develop mercury pretreatment programs at wastewater treatment plants (WWTP). Some WWTP are now requiring monitoring of mercury levels entering the public sewer system, and some systems have set limits on the levels of mercury allowed to enter the sewer system. The Agency has recently lowered the threshold for reporting mercury emissions to the Toxic Release Inventory, which began in 2000. The lower threshold will help ensure that citizens know about significant mercury emissions in their communities.

Planned Actions to Reduce Mercury Pollution

In addition to developing regulations to limit mercury emissions from utilities, EPA has developed an action plan to address other sources of mercury pollution. Already there are a number of planned activities under way: EPA is developing a revised human health-based mercury standard for water quality and has identified the need to develop a standard that will protect wildlife from mercury's effects.

EPA is making meaningful progress in addressing the mercury pollution problem in the United States and is exploring the regional, intercontinental and global dimensions of this problem. EPA is committed to increasing public awareness about the dangers associated with exposure to mercury and will continue to take actions that will provide increased protection of public health.

1.3 Mercury Amalgam in Dental Offices

Mercury amalgam is a major material used in dental offices throughout the United States. The amalgam can enter the wastewater at a dental office either during the removal process, when old amalgams are removed or during the placement process when new amalgam is used. In a modern dental office, a vacuum system is used to remove liquid and particulate, including mercury amalgam, that accumulate in the mouth during dental procedures. The liquid contains particles of mercury amalgam of varying size. A coarse chair side trap is used to remove very large particles from the vacuumed liquid and to protect the vacuum lines from becoming plugged. The liquid and small particles are carried through the vacuum system to an air/water separator near the central vacuum pump for dry systems or directly to the vacuum pump in a wet system. The wastewater carrying the mercury material is then typically discharged to the sanitary sewer or septic tank system along with other wastewater from the office or building. Most of the mercury present in the wastewater is in the particulate form (insoluble). The larger particles are settleable and can be trapped in sedimentation chambers/devices that provide quiescent conditions. Smaller particles (>0.45 micron) are also present, contain mercury, and will pass through settling devices and contribute to the total mercury load in effluent from these devices. Some portion of these smaller particles can be filtered by various filtration systems. Data collected over the past few years has shown that a small amount of mercury will also be present in the soluble form (either dissolved or in particles < 0.45 micron in size).

Chapter 2 - Technology Description and Operating Processes

2.0 Technology Description

The package treatment unit evaluated during the verification test was the DRNA Mercury Recovery Unit (MRU). This unit is sold by DRNA as a complete package that can be installed upstream of the air/water separator of dry vacuum systems or before the filters and vacuum pump in a wet system commonly used at dental offices. The MRU is comprised of two main treatment components - a BullfroHg amalgam separator for particulate removal based on the sedimentation process, and a mercury filter unit containing an adsorbent material for soluble mercury removal and a fine particulate filter. Figure 2-1 shows a picture of the MRU unit. This combination of technologies addresses both insoluble and soluble mercury typically present in the wastewater from dental office vacuum systems.

2.1 DRNA Mercury Recovery Unit (MRU)

The BullfroHg is a combined solid and air/water separator designed for installation on the vacuum side of a dental vacuum pump to remove mercury amalgam particles from dental wastewater. Three-phase flow (air/water/solids) enters the BullfroHg from the dental office vacuum line. The entrained solids and liquids are retained within the BullfroHg while the air flows out to the system vacuum pump. Particles are allowed to settle for several hours after the vacuum system is shutdown at the end of the operating day. At the conclusion of the settling time, a timer activates a pump to transfer the wastewater from the settling chamber through two adsorbents (carbon and a proprietary resin) and through a fine particle filter. Solid amalgam particles remain trapped within the separator unit.

Soluble mercury present in the wastewater is adsorbed onto two types of media. The wastewater first passes through granular activated carbon and then through a proprietary resin designed to specifically adsorb mercury. A fine particulate filter made of progressive density polypropylene, nominally rated at 1 micron, is located after the resin to capture any particulate in the effluent or from the absorption zone of the adsorbent column. The treated wastewater exits the adsorbent filter and discharges to the sewer system. A bleach solution is added to the filter unit to control biological growth in the media.

Mercury retained in the BullfroHg sedimentation chamber and captured on the adsorbents and filter can be returned to DRNA for recycling. DRNA has arrangements with mercury recovery companies to recycle the mercury trapped or adsorbed by the MRU and captured by the chair side traps that are part of a typical vacuum system. The mercury recovery/recycling process was not part of this verification process.

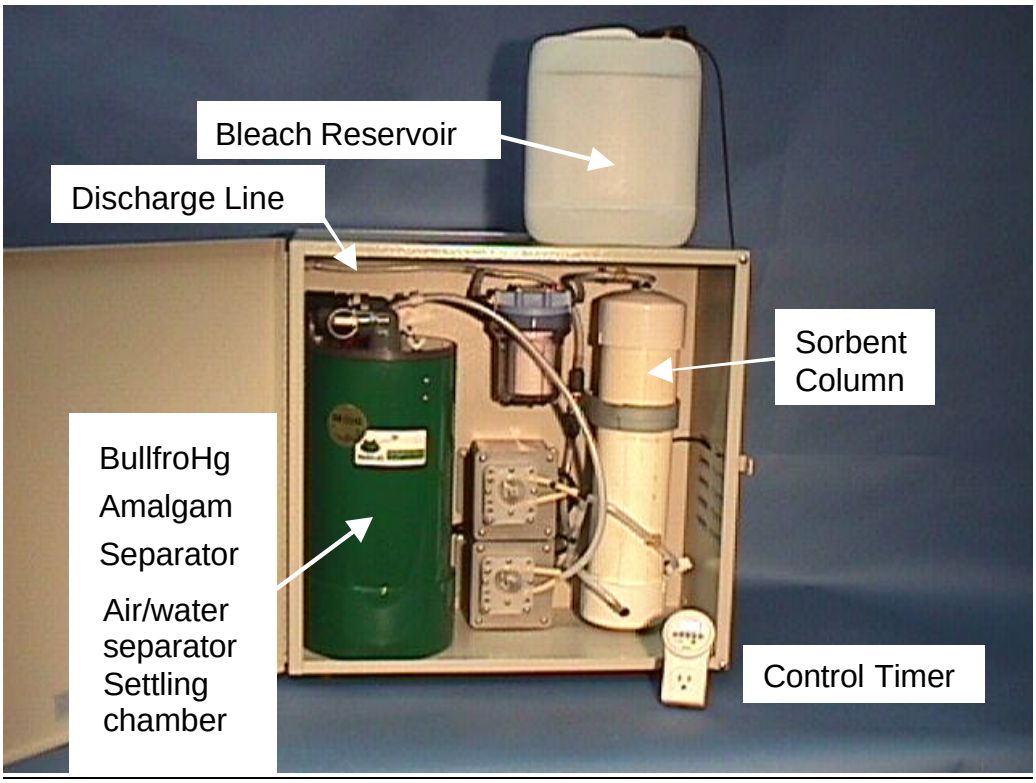
The MRU is designed to remove fine amalgam particles that can damage a vacuum pump in a wet vacuum system. The MRU is designed so that flow will bypass the MRU and allow continued operation of the dental suction system if any problem occurs with the unit. This bypassed water will not have particulate removed and will be filtered either by the filter before a wet vacuum pump or by the air/solids separator in the dry system, assuming the original

separator remained inline after MRU installation. The MRU is a self-priming system and holds a vacuum when turned off. The MRU system pump can run dry without damaging the motor or the drive unit.

The system timer controls both the bleach pump and the settled wastewater transfer pump. The timer can be set to initiate the pumping of settled wastewater to the adsorbent column at a predetermined time each day. The timer is set at the factory to start the pumping cycle at 3 a.m., which provides about 10 hours of settling time for an office that closes at 5 p.m.. The timer also turns off the pump based on the programmed time and is normally set to shut down the pump after two to three hours of operation. The pump is also shut off by the low level sensor in the BullfroHg, which detects the presence of liquid in the settling chamber. If liquid is not present, the MRU pump will not activate or will shut down if operating.

The bleach system is designed to operate using normal household or commercial bleach. The bleach solution is pumped into the wastewater as it is transferred from the BullfroHg separator to the adsorbent column to control bacterial growth in the adsorbent system. Bleach can affect the solubility of mercury, causing particulate mercury to be dissolved or leached into solution. The bleach may also oxidize some of the organics in the wastewater, which could have a negative effect the adsorption of mercury on the proprietary resin. When the verification test began the O&M manual recommended using one part bleach to one part water. This ratio was changed during the test to one part bleach to two parts water. The current recommended method for making the bleach solution is to mix one part bleach with three parts water.

Figure 2-1. DRNA Mercury Recovery Unit (MRU)



2.2 Equipment Specifications

The equipment specifications for the MRU are given below. Table 2-1 lists the components and parts that are included with an MRU as shipped to a dental location.

Physical Dimensions:

Height	24 inch (61 cm)
Width	24 inch (61 cm)
Depth	12 inch (31 cm)
Capacity	10 liters per day / up to six chairs (operatories)
Weight	90 lbs (41 kg)
Vacuum Rating	15 inch Hg
Pressure Rating	not rated
Temperature Range:	40-104^{o}F / 4-40^{o}C

Electrical Requirements:

Input Voltage	4 amp, 120 VAC

Table 2-1. Equipment List

Description
MRU Enclosure containing: • BullfroHg™ Air/Water/Amalgam Separator • Twin peristaltic pumps with waste sensor • 10-liter bleach reservoir • Adsorbent column • Particle filter
Instruction Manual
Fittings & Hose: • 1" hose barb x female cam-lock fitting • 1" hose barb x male cam-lock fitting • 1" x 1" hose barb coupling • 1" hose clamps • 1" ID x 6-ft long vacuum hose • ¼" ID x 6-ft long discharge hose • 1" x 1" x ¼" hose barb for discharge connection • 1" x ¾" hose barb coupling (to adapt to ¾" ID hose)
Programmable Timer/Controller

Each standard MRU unit is designed to handle the flow for up to six (6) operatories (chairs). DRNA must be consulted for larger clinics.

2.3 Operation and Maintenance

The MRU is designed for ease of operation and minimal maintenance once installed in the vacuum system. The unit is plumbed into the vacuum system ahead of the vacuum pump and upstream of the air/water separator if one is present. The system is self-contained and operates automatically based on a timer that activates the pump that removes water from the separator unit and pumps it through the filter and adsorbent material. No daily operator intervention is required other than to conduct periodic checks that the timer, tubing, and pumps are working properly. The operator does need to check the bleach solution on a regular basis (requires replenishing about once per month). The installation, operation and maintenance manual is presented in Appendix A.

Maintenance activities are minimal for the MRU. The large surface area of the adsorbent provides possible sites for biological growth. If biomass builds up on the adsorbent, it can reduce the adsorbent's effectiveness of the adsorbent for the removal of soluble mercury. The biomass can also cause the column to plug, reducing the flow rate of treated wastewater through the unit. A bleach solution is used to disinfect the adsorbent system and help reduce clogging. This solution needs to be prepared periodically (about once per month in normal use) and placed in the container that is supplied with the MRU. Replacement should occur whenever the volume in the container becomes low. The original recommended formula for this solution was one part

commercial bleach and one part water. DRNA has subsequently changed the recommended solution to one part commercial bleach and three parts water. The bleach concentration was changed during the verification test as discussed in section 4.7. The tubing that runs through the pump needs periodic replacement (approximately once per year), as it will become worn over time. The recommended maintenance activities and schedule are shown in Table 2-2.

Table 2-2. Recommended Maintenance Schedule

Item	Required Maintenance	Recommended Interval*
Pump (s)	Replace pump tubing with new section of tubing.	12 months
Bleach Reservoir	Add 1 part commercial bleach, 3 parts water.	Check volume weekly
BullfroHg™ Separator	Recycle	6 to 12 months
Adsorbent Column	Recycle	6 to 12 months
Particle filter	Replace	6 to 12 months

***** Actual interval may vary depending on the type and amount of wastewater treated

The MRU system is designed so that operators are not exposed to any residues and do not have to open any mercury contaminated equipment. DRNA ships a complete replacement adsorbent column, filter and BullfroHg when it is time to recycle these devices. When the replacements arrive, the operator exchanges the new BullfroHg, adsorbent column, and filter for those in the MRU. Disinfectant is placed in the separator prior to recycling the unit. The amalgam separator is first sealed in a 4-mil plastic bag containing an adsorbent. This bag and adsorbent provide secondary containment in the event of a leak. The unit is then packed in a 275#, heavy-wall box with custom-made foam padding to protect the separator from damage during shipping. It is labeled as amalgam for shipping. DRNA then arranges for the residues from the units to be removed and recycled/reclaimed.

2.4 Vendor Claims

DRNA states in its literature that the mercury amalgam separator is effective at capturing 95 percent of all particles that are greater than 10 microns in size. DRNA states that these particles (>10 micron) typically account for 95 percent of the total mercury sent to the unit. Further, the mercury specific adsorbent column typically reduces the mercury concentration in the treated wastewater to below detection limits (author's statement – MDL for mercury is typically less than 0.2 µg/L).

The verification testing process did not measure particle size distribution, but did measure the total mercury load (soluble and insoluble) in the wastewater during the characterization period. The total mercury (filterable, settleable, and soluble) in the treated wastewater after treatment by the MRU was measured during the verification test period. The results of the verification test

determined the amount of mercury removed by the MRU during operation at the dental office and the total mass balance for mercury during the verification period.

The vendor has stated that the DRNA BullFroHg (the solids separator) is ISO 11143 certified. A statement from the annex to a report indicating the certification was provided to NSF. The ISO certification report was not reviewed or confirmed. A copy of the information provided is given in Appendix A with the O&M manual.

Chapter 3 - Methods and Test Procedures

3.0 Test Plan and Procedures

A VTP was prepared and approved for the verification of the DRNA MRU and is attached in Appendix B. This VTP, "Verification Test Plan for The Dental Recycling North America Mercury Removal System, June 2001"[1] detailed all of the procedures and analytical methods that were to be used to perform the verification test. The VTP was prepared in accordance with the SWP protocol, "Protocol for the Verification of Mercury Amalgam Removal Technologies, April 2001"[2]. The VTP included tasks designed to verify the mercury removal capability of the MRU and to obtain information on the installation, operation, and maintenance requirements of the MRU. There were three distinct phases of fieldwork that needed to be accomplished as part of the VTP: initial characterization of the wastewater, installation and start-up of the MRU, and verification testing with the MRU operating and treating the wastewater.

Each of these testing elements, performed during the technology verification, are described in this section. In addition to a description of the sample collection methods, equipment installation, and equipment operation, this section also describes the analytical protocols. Quality Assurance and Quality Control procedures and data management approach are discussed in detail in the VTP.

3.1 Influent Characterization - Procedures

3.1.1 Introduction

The purpose of influent characterization testing was to obtain an understanding of the influent wastewater volume and water quality characteristics before the verification test of the DRNA MRU. There was no analytical data available for the wastewater from the test site prior to the test. Therefore, a thorough characterization of the influent (untreated) wastewater was needed to provide credible information for determining the mercury removal effectiveness of the MRU. Influent characterization occurred during a 44-day business period (eleven weeks) before the MRU was installed for testing.

3.1.2 Objectives

The objectives of influent characterization were to:

- Determine the daily flow of the wastewater stream to be used for verification testing;
- Evaluate the concentrations and daily mass loading of mercury in settleable, filterable and soluble forms;
- Determine operational conditions for the MRU technology;
- Record and document all influent characterization conditions and results;
- Identify any required modifications to the VTP prior to beginning verification of the MRU (adjustments in sampling, analysis, etc.); and,
- Provide a basis for evaluating the removal efficiency of the DRNA MRU.

3.1.3 Sampling Location, Container Type, and Sampling Frequency

The dental office selected as the site for this verification test operated a dry vacuum system with an air/water separator upstream of the vacuum pump. The vacuum collection system piping was one inch diameter PVC pipe located in the office floor. Flexible one inch plastic pipe connected the chair side trap unit to the main collection piping in the wall. The office is located on the first floor and all piping and the vacuum system are located on the first floor. A 10-liter vacuum-rated polypropylene container was used for the sample collection container. The container was plumbed into the vacuum system just prior to the current air/water separator collection vessel and was set up to maintain the vacuum in the system. Therefore, if the bottle were to overfill, the extra wastewater would be collected in the current system prior to reaching the vacuum pump. The entire flow during a 24-hour period of operation was collected to characterize the wastewater. Collection of the entire flow eliminated concerns about obtaining non-representative samples that could contain large heterogeneous particles and eliminated the need to consider flow weighted composite samples versus time composite samples. The use of the 10-liter container ensured that sufficient volume was available to contain all of the flow for a full day of office activities. The typical flow in the system was 2-3 liters per day (½ to ¾ gallons) with a potential for an additional 2.5 liters of flushing solution on line cleaning days. Sample volume did not exceed the container capacity during the test period.

The sample location for this verification test was located upstream of the air/water separator as the DRNA MRU is designed to be installed before the air/water separator. Therefore, the characterization sampling location was the same as the inlet location of the MRU during the verification test. By placing the sample bottle at this location, the wastewater sampled during the influent characterization was as similar as possible to the wastewater that entered the BullfroHg separator in the MRU. The elevation of the sample container inlet (approximately three feet above the floor) was located at a height similar to the inlet of the MRU air/water/solid separator for this installation. The inlet to the original dry system air/water separator was approximately four feet above the floor. The wastewater that was being collected in the sample container was the same wastewater that is normally collected in the dental office air/water separator, and discharged to the public the sewer system in the absence of a treatment system.

The dental office normally operated from 8 a.m. to 5 p.m. The sample container was changed daily at the end of the office-operating day. The daily sample, representing all of the previous 24-hour flow, was capped and prepared for shipment to the laboratory. A chain of custody form was prepared daily and signed by the sampler and by a witness. In addition, a custody seal was placed over the cap of the container when the cap was placed on the bottle. Each sample bottle was placed in a cooler with ice for shipment to the laboratory and was delivered to the NSF laboratory within a few hours by a courier service.

After receipt at the laboratory, the contents of the 10-liter sample collection container were poured into a 7 gallon rectangular polypropylene settling tank and allowed to settle for 8 to 16 hours. The supernatant in the settling tank was decanted into a 2 L polypropylene graduated cylinder using a variable speed peristaltic pump and food grade Tygon® tubing. The supernatant was transferred from the graduated cylinder to a clean 10 L polypropylene container, which was agitated using a circular motion for 30 seconds, and three individual samples of the supernatant

were poured into 125 mL HDPE bottles containing 2.5 mL of 50 percent (by volume) nitric acid. These samples were for total mercury analysis. Approximately 400 mL of the supernatant was passed through pre-weighed glass fiber filters under vacuum as needed. The filtrate was poured in to a polypropylene beaker, and three samples were created by agitating the beaker for 30 seconds and pouring the filtrate into 125 mL HDPE bottles containing 2.5 mL of 50 percent (by volume) nitric acid. The filters were dried and weighed and the weight of the filtered solids was recorded.

Solids remaining in the settling tank were transferred to a polypropylene beaker using mercury-free water to rinse the solids remaining in the tank into the beaker. The rinse bottle and beaker were weighed prior to rinsing the settling tank and the initial tare weights were recorded. After the contents of the settling tank had been transferred into the beaker, both the rinse bottle and beaker were weighed again. The solids wet weight was calculated by subtracting the weight of the rinse water used and the tare weight of the beaker from the final weight of the beaker. The solids and rinse water were filtered through glass fiber prefilters and then through 0.45 micron membrane filters. The filters and retained solids were oven dried for a minimum of 24 hours, then weighed to the nearest 0.1 mg. The filters were placed in a plastic bag and delivered to the laboratory for digestion and analysis.

The Laboratory weighed aliquots of the solids and filter samples. These samples were digested and the mercury concentration was determined. In most cases, all of the collected solids were included in the digested sample. In a few cases, the sample size was too large for a single digestion, and a representative cross section of the filtered solids was digested. The representative sample was typically at least 50 percent of the total solids collected.

The complete sample settling and handling procedures are presented in Appendix C.

The sampling container(s) and any fittings were cleaned by the laboratory and returned to the field for reuse. Cleaning involved scraping to remove any solids adhered to the surface of the container or fittings and rinsing with mercury-free water (<0.2 µg/L). All solids collected during cleaning, along with all the rinse water, were added to the sample being settled and included in the analysis. The method used to clean the sampling container(s) is described in Appendix C. Rinse water volumes and weights were recorded so that dilution by the rinse water could be accounted for and the data adjusted accordingly. Copies of the spreadsheets showing these calculations are presented in Appendix D.

New chair side traps were installed just before the start of the influent characterization program. These traps were changed approximately once per week, in accordance with normal office procedures. The trap, with the amalgam and related materials, was placed in sealable plastic bags and transported to the laboratory for weighing. A log was maintained by the dental office to document the replacement of the chair side traps.

3.1.4 Analytical Testing and Record Keeping

Forty-four samples were collected during an eleven-week characterization period. Table 3-1 presents the influent parameters measured for the solids collected and the liquid sub-samples. Industry standard procedures (USEPA Methods [3,4,5] or Standard Methods [6]) were used for sample analysis. Table 3-2 shows the specific method numbers used for the mercury and pH analyses. The procedures were checked using standard reference solids samples containing known amounts of mercury and by testing a sample of the actual mercury amalgam from the dental office. All liquid samples were analyzed in triplicate for mercury.

Table 3-1. Summary of Influent Analytical Requirements

Parameter	Solid Fraction[1]	Liquid Fraction[1]
Volume (liters) [2]		X
pH		X
Approximate volume of solids (particle(s)) (mL) [3]	X	
Wet weight of solids (grams)	X	
Solid (Particle) mercury (mg) [4]	X	
Total mercury (mg/L) [5]		X
Soluble mercury (mg/L) [5]		X
Chair side Trap Material – weight (grams)[6]	X	

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 after settleable solids removed.

(6) Chair side trap material weighed

The dental office staff maintained a record of the number of amalgams and surfaces placed and removed each day. A copy of the log was obtained each day when the sample was collected. Copies of the dental amalgam logs are presented in Appendix E.

The dental assistant was responsible for the flushing procedure, which was performed on a regular basis in accordance with office procedures and observed by the TO field representative. Using a "calibrated" bottle, the volume was standardized at 500 mL per chair. The cleaning

solution used was the brand name PureVac. The material safety data sheet for PureVac is provided in Appendix F.

Table 3-2. Analytical Methods and Detection Limits

Sample Matrix	Analyses	Standard Methods USEPA Methods	Detection Limit
LIQUID	pH Mercury (Total) Mercury (Soluble)	150.1 7470A/245.1 7470A/245.1	N/A (range 1-13 S.U.) 0.2 µg/L 0.2 µg/L
SOLID	Mercury (Total) TCLP	7471A/245.5 1311	0.25 mg/kg N/A

3.2 MRU Installation and Commissioning - Procedures

3.2.1 Introduction

DRNA provided an installation, operation, and maintenance manual for the MRU. This manual is presented in Appendix A. A new MRU unit with all components was shipped to the site by DRNA. The installation and startup were straightforward, as described in Section 3.2.3 and in the installation manual. A representative from NSF was present at the site during installation to confirm that the installation was in accordance with the VTP and the DRNA O&M manual.

3.2.2 Objectives

The objectives of the installation and start-up phase of the VTP were to:

- Install the Mercury Recovery Unit (MRU) in accordance with the DRNA O&M manual;
- Start-up and test the MRU to ensure all processes were operating properly, timers were set for proper automatic operation, and any leaks that occurred during the installation were eliminated;
- Make any modifications needed to achieve operation; and,
- Record and document all installation and start-up conditions prior to beginning the verification test.

3.2.3 Installation and Startup Procedures

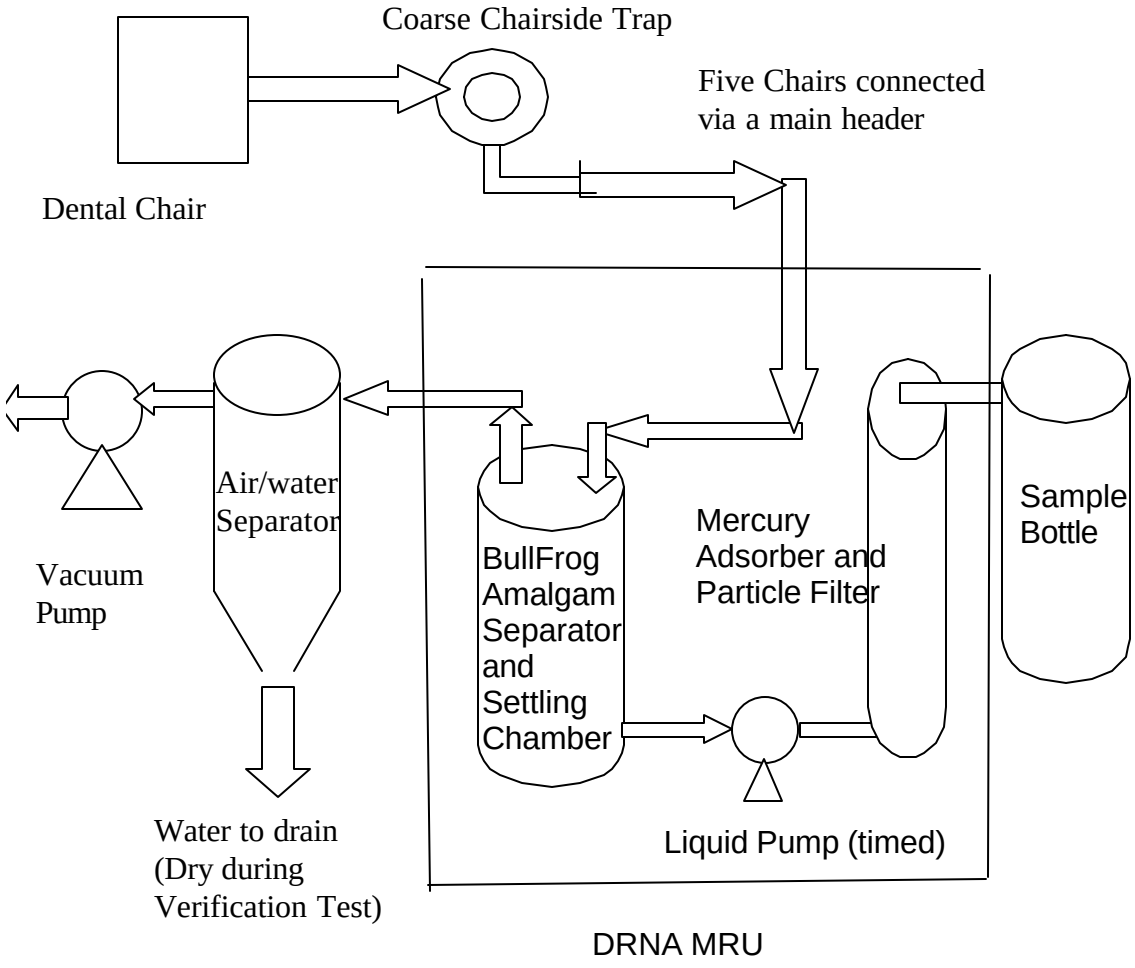
The installation and start-up of the MRU was performed by the Testing Organization's field support person and was observed by the NSF staff. No on site support was needed from DRNA. The MRU, as shown previously in Figure 2-1, was shipped as a self-contained unit that required connections to the vacuum system using standard tubing and fittings. Installation was at the same location in the vacuum system as the sample container used for the characterization testing. The sample container connections were removed and the proper connections for the MRU were installed. The entire installation and system checks took less than three hours.

A new, clean MRU system was installed in the vacuum line upstream of the existing air/water separator, as recommended by DRNA. The one-inch vacuum line was connected to the inlet of the MRU with a one-inch quick-connect connection, which is the standard inlet size for the MRU. The outlet vacuum port on the MRU was connected to the one-inch line running to the current air/water separator. The air/water separator remained in-line downstream of the MRU as a protection for the vacuum pump in the case the settling unit should overflow. The schematic of the DRNA system installation is shown in Figure 3-1.

The internal units and pumps in the MRU came ready for connection and operation. Tubing was supplied with fittings to connect the outlet port of the BullfroHg separator to a small pump, which pumps the wastewater through the adsorbent and filter unit. The pump and timer components arrived ready for use with the timer preset for activating the pump to transfer the settled wastewater to the adsorbent column. The treated effluent discharge line from the MRU was directed into a 10-liter polypropylene container that collected all of the effluent from each twenty-four period of dental office operation. The sample bottle was located at the utility sink so that in the case of an overflow the treated water would discharge to the sink and the sewer system. No overflows occurred during the testing period.

Once the installation was complete, the timer was checked and set to activate the pump at 3 a.m.. The waste level sensor in the separator shuts the pump off when all wastewater is removed from the separator. The sensor and timer were checked for proper operation in accordance with the installation manual. The entire system was wet tested. Clean water was placed in the separator unit and the vacuum lines were reconnected with the fast connect/disconnect fittings. The manual operation button was pushed which activated the pump and clean water was pumped through the adsorbent filter, particle filter, and into the sample collection bottle. The MRU was inspected for leaks and no leaks were found. Once the system checks were completed, the MRU was ready for operation and the verification-testing period started.

Figure 3-1. MRU Installation Schematic Diagram



3.3 Verification Testing - Procedures

3.3.1 Introduction

The verification test period was designed to measure treatment performance of the DRNA MRU under field conditions. The treated wastewater effluent discharged from the MRU was collected and analyzed every day the dental office was operating. Residuals retained by the MRU in the separator, particle filter, and adsorbent filter (four separate samples, note that the adsorbent filter

contained two materials) were collected and measured individually, and analyzed individually at the end of the verification test. All samples of wastewater and residue were analyzed to determine the performance of the MRU for the removal of mercury from the dental office wastewater vacuum systems.. Operation and maintenance conditions were monitored and documented. Verification testing conditions, observations and results are presented in this Verification Report in Chapter 4, Results and Discussion.

3.3.2 Objectives

The objectives of verification testing were to:

- Evaluate the treatment performance of the MRU for the removal of soluble and insoluble mercury, operating under standard conditions as specified by DRNA;
- Evaluate the MRU operation and maintenance requirements; and
- Record and document test conditions, observations and results

3.3.3 Sample Location, Sampling Approach, and Frequency

3.3.3.1 Treated Water Sample Collection

The installed DRNA MRU collected the entire day's flow of wastewater from the vacuum system and retained the liquid and solids in the BullfroHg separator. After several hours of settling, from approximately 5 p.m. until 3 a.m., the liquid in the separator was pumped through the adsorbent filter and particle filter unit. The pumping time was typically 2-4 hours, resulting in an empty BullFroHg Separator (except for retained settled solids) and filled sample container by 7 a.m. The sampling location for the daily treated-water discharge was from the end of the discharge tube from the MRU unit. The treated effluent would normally discharge directly to the sewer system, but for this test, the discharge tube was secured in a 10-liter polypropylene sample bottle that collected the entire volume discharged from the system. Each sample represented a 24-hour period comprised of one day of operation at the dental office, followed by overnight treatment in the MRU. During the verification testing period, the sample was retrieved in the morning after the treatment was completed, and the samples were sent to the laboratory by courier service.

Collection of the entire flow for each 24-hour period eliminated any concern about obtaining "representative" subsamples and eliminated the need to consider flow weighted composite samples or time composite samples. The use of the 10-liter container provided sufficient volume to contain all of the flow for a full day of office activities. The typical flow in the system was 2 – 3 liters per day (½ to ¾ gallons) with an additional 2.5 liters of flushing solution on line cleaning days. At no time during the test did the sample container approach being completely full or overflow.

Effluent samples were collected for 32 days to yield 32 samples for analysis. At the end of each 24-hour period of office and MRU operation, the filled sample bottle was replaced with a clean sample bottle. The filled sample bottle was capped and prepared for shipment to the laboratory. A chain of custody form was prepared and signed by the sampler and a witness, and a custody

seal was placed over the cap of the container. The sample bottle was placed in a cooler with ice and remained cool during shipment to the laboratory. The wastewater was delivered to the NSF laboratory by a courier service and generally arrived within a few hours of sample collection. After logging the sample in at the NSF laboratory, recording the temperature of the sample, and noting the cooler condition, the entire sample was transferred to a plastic settling tank (12 inches x 12 inches x 12 inches). The sample was settled and the sampling container was cleaned following the same procedures used during the characterization period, as described in Section 3.1.3. Sample containers were checked for residual mercury contamination by adding distilled water to selected bottles after they were cleaned. The "blank" was then allowed to sit in the bottle for several hours. The bottle blank(s) were then sent to the laboratory for analysis.

3.3.3.2 Residuals Sample Collection

The DRNA MRU is designed to retain solid amalgam and other dental waste particles in the BullfroHg separator and the particle filter. The system is sized to retain these residuals for a six month to one-year period. At that time, the separator, particle filter, and adsorbent filter units are returned to DRNA for reclamation of mercury and silver in the amalgam and cleaning. Cleaned units are provided to the dental office to replace the used units. The recycle/reclamation of mercury and silver was not part of this verification.

Based on this normal operating condition, the residuals from the separator, particle filter, and adsorbent filter were scheduled to be collected one time at the end of the verification test. At the end of the verification test and after the final line flushing to remove any residues in the vacuum lines, the MRU pump was manually activated to remove any wastewater present in the separator. The pumped wastewater was collected in the sample bottle for the last day of the verification test. Once all of the water had been removed, the BullFroHg separator unit, the particle filter, and the adsorbent unit were disconnected and removed from the MRU housing. Replacement units and filters were provided by DRNA and were installed in the MRU housing at the dental office. The test units used during the verification test were then taken to the NSF laboratory for residuals sampling and analysis. An NSF representative was present during the dismantling of the equipment at the dental office and drove the equipment containing the residuals to the NSF laboratory under chain of custody.

The BullFroHg separator unit is designed for ease of cleaning and reuse with a removable lid that allows ready access to the unit. At the laboratory, the separator unit was opened and the entire residue from the separator was removed and collected as sample. The separator walls were scraped and cleaned to remove the residue, which was added to the separator residue sample. After scraping, the separator was rinsed and the rinsate added to the wet solids. The residue and liquid were placed in containers and dried at low temperature until the moisture was removed. The dried solids were then well mixed in preparation for sampling. Six subsamples of the residue were collected over the surface and depth of the residue and sent to the laboratory for mercury analysis. The original plan was to also perform TCLP analysis on the residue but there was insufficient sample to perform the TCLP analysis. While information on the leachable level of mercury in the residue would have been of interest, all mercury retained by the MRU is typically

recycled and is not disposed of in landfills. Therefore, the TCLP results do not have a direct impact on the methods used for disposal of the residues.

The particle filter (nominally rated at 1 micron) contained a heavy load of small particles that did not settle in the separator or were from the carbon and resin material in the adsorbent column. The filter was removed from the unit (threaded connection) and placed in a pan for drying. The filter was dried at low temperature and a final dry weight obtained. The filter was then divided into sections (six samples) and three samples were sent to the lab. The other three samples were held to determine if they required analysis. The decision not to analyze additional samples was based on the reasonable reproducibility of the three samples selected for analysis. The samples were weighed and digested using the mercury solids procedure (EPA 245.5), in order to determine the mass of mercury present in the particle filter subsample. The average concentration of mercury in the filter samples (on a filter weight basis, i.e. mg/kg) was then used to determine the total mass of mercury present on the entire filter.

The adsorbent material (carbon and resin) adsorbed soluble mercury that may have been present in the wastewater. The adsorbents were removed from the filter housing, keeping the carbon and resin separate as much as possible. Each residue was placed in a dish, dried at low temperature, and weighed in the laboratory. The material was thoroughly mixed and six subsamples of each adsorbent (resin and carbon) were taken for analysis. The six samples were digested and measured for mercury concentration. The average concentration of the six samples was used with the total dry weight of adsorbent to calculate the mass of mercury collected by the adsorbents.

New chair side traps were installed just before the start of the verification test. These traps were changed a regular basis, approximately once per week from July 27 through September 19, 2001, in accordance with normal office procedures. The trap, with the amalgam and related materials, was placed in sealable plastic bags and transported to the laboratory for weighing. A log was maintained by the dental office to document the replacement of the chair side traps.

3.3.4 Analytical Testing and Record Keeping

A total of 32 samples were collected over a seven-week verification period. Table 3.3 presents the effluent parameters that were measured for the solids collected and liquid sub-samples. Industry standard procedures (USEPA Methods[3,4,5] or Standard Methods[6]) were used for sample analysis. The method reference numbers are shown in Table 3.2. The procedure for the digestion of solids for mercury analysis was checked using standard reference solids samples containing known amounts of mercury, and by testing a sample of the actual mercury amalgam form the dental office. All liquid samples were analyzed in triplicate for mercury.

Table 3-3. Summary of Effluent and Residual Analytical Requirements

Parameter	Effluent[1, 2]		Residuals	
	Solid Fraction	Liquid Fraction	Solid Fraction	Liquid Fraction
Volume (liters)[3]		X		X
pH		X		X
Approximate volume of solids (particle(s)) (mL)[4]	X		X	
Wet weight solid particles (grams)	X		X	
Solid (particle) mercury (mg)[5]	X		X	
Total mercury (mg/L)[6]		X		X
Soluble mercury (mg/L)[6]		X		X
TCLP[7]			X	
Chair side Trap material weighed (grams)[8]			X	

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 (not completed due to insufficient sample weight).

(8) Chair side trap material were collected and weighed. Paper and non-amalgam/tooth debris were excluded from the sample.

The dental office staff maintained a record of the number of amalgams and the surfaces placed and removed each day. A copy of the log was obtained each day when the sample was collected. Copies of the dental amalgam logs are presented in Appendix E.

The dental assistant was responsible for performing the flushing procedure, which was performed on a regular basis, as described in Section 3.1.4.

3.3.5 Operation and Maintenance Performance

Both quantitative and qualitative performance of the MRU was evaluated during the verification test. The MRU was self-contained and designed to have minimal operator intervention once the installation was complete. As stated earlier, a field log was maintained that included all observations made during the installation, startup and operation of the MRU. Observations regarding the condition of the MRU, any changes in the setup or operation (timer adjustments, filter changes, etc.), or any problems that required resolution were recorded in the log by the field personnel.

Qualitative operation and maintenance performance information included:

- Observations regarding ease of operation;
- Observations regarding the effect of the MRU, if any, on the operation of the vacuum system;
- Documentation of any operating problems encountered during testing;
- Quality of the O&M manual (e.g., actual experience in the field compared to that indicated in the manual, clarity of instructions); and,
- Observations regarding labor requirements.

Several quantitative performance measures were evaluated for the operation of the MRU. The information included:

- Duration (in hours) of any clean-out operations (none were expected based on equipment design, length of test, and vendor information);
- Frequency and duration (in hours) of any preventative or breakdown maintenance activities;
- Electrical consumption for the two pumps was projected by estimating the operating time of the pumps (timer controlled), and calculating kilowatt hours consumed by using the electrical rating for the pumps and hours of operation;
- Chemical consumption of the bleach cleaning solution was monitored by logging the quantity of solution made and the remaining material in the container at the end of the verification test; and,
- Records of any other consumables used by the MRU over the test period (none were expected).

Chapter 4 - Results and Discussion

4.0 Characterization Test

The wastewater characterization test began on July 10, 2001 and continued through September 21, 2001. A total of 44 samples were collected during the eleven-week period. The dental office normally operated only 4 days per week and samples were collected at the end of each normal business day. Two of the samples were collected on days when the dentist was not in the office and only hygiene activities occurred. These two days, August 6 and 23, had two of the lowest total flows during the characterization.

4.1 Mercury Amalgams Removed and Placed

Two rooms out of the five rooms in the office were used as operatories during the characterization study. Records of the number of surfaces placed or removed, and the tooth number(s) for each procedure for each day were kept by the dental technician. Table 4-1 shows the number of surfaces removed and placed during the characterization test. Three hundred thirty-four (334) surfaces over 42 operating days were removed/placed during the sampling period. This represents an average of 7.95 surfaces per day or approximately 40 surfaces per week on a 5 operating days per week basis. There were three sampling days when no surfaces were removed or placed. On two of these days (August 6 and 23), only hygiene activities occurred at the office (no dentist in) and there was one day (August 7) of normal office operation when no mercury amalgam surfaces were removed or placed.

4.2 Mercury Results

Each sample collected for wastewater characterization was divided into two phases for mercury analysis, the settled solids fraction and the liquid fraction. Upon arrival at the laboratory, the sample was placed in a settling chamber and the solids were allowed to settle for eight to sixteen hours (See Procedure for Separation of Mercury Amalgam Samples in Appendix C). The liquid fraction was then decanted and set aside for filtration and mercury analysis. Care was taken to remove as much free liquid as possible, but some free liquid was allowed to remain in the settled solids to minimize disturbing the solids. The settled solids sample was then filtered using a 0.45 micron filter to remove the free liquid. The solids were dried and weighed prior to analysis for total mercury.

The liquid fraction was divided into two samples. One sample was subsampled in triplicate and sent to the laboratory for total mercury analysis. The other sample was filtered through a 0.45 micron filter and then subsampled in triplicate for soluble mercury analysis. Soluble mercury is defined as mercury that is either dissolved in the wastewater or associated with particulate that is less than 0.45 micron in size. Using a 0.45 micron filter is the standard USEPA approach for preparing a soluble mercury sample. All sub sampling was performed by thoroughly mixing (shaking) the sample bottle and then quickly pouring the liquid sample into three bottles.

Table 4-1. Summary of Number of Surfaces Removed and Placed - Characterization Test

Date	Operatory Room 1			Operatory Room 2			Total Surfaces
	Surfaces Removed	Surfaces Placed	Notes	Surfaces Removed	Surfaces Placed	Notes	
7/10/01	0	2		0	0		2
7/11/01	6	3		4	3		16
7/12/01	4	0		0	0		4
7/13/01	2	5		6	7		20
7/16/01	3	5		0	3		11
7/17/01	2	0		2	7		11
7/18/01	7	0		4	5		16
7/20/01	0	0		6	0		6
7/23/01	2	0		0	4		6
7/24/01	2	0		0	0		2
7/25/01	0	0		6	0		6
7/27/01	0	0		0	2		2
7/30/01	3	0		7	6		16
7/31/01	1	0		7	0		8
8/1/01	0	0		0	4		4
8/3/01	3	0	(1)	4	0	(1)	7
8/6/01	0	0	(2)	0	0	(2)	0
8/7/01	0	0		0	0		0
8/8/01	0	0		0	2		2
8/9/01	0	0		6	4		10
8/10/01	0	0		3	0		3
8/13/01	3	2		1	0		6
8/14/01	1	5		0	0		6
8/15/01	2	2		2	7		13

Table 4-1. (continued) Summary of Number of Surfaces Removed and Placed - Characterization Test

Date	Operatory Room 1			Operatory Room 2			Total Surfaces
	Surfaces Removed	Surfaces Placed	Notes	Surfaces Removed	Surfaces Placed	Notes	
8/17/01	5	0		0	0		5
8/20/01	0	0	(1)	3	0	(1)	3
8/21/01	3	8		4	0		15
8/22/01	0	2		0	6		8
8/23/01	0	0	(2)	0	0	(2)	0
8/24/01	5	6		0	0		11
8/27/01	11	0		0	0		11
8/28/01	7	0		3	3		13
8/29/01	0	1		0	0	(3)	1
8/31/01	3	0		2	0	(3)	5
9/4/01	4	0		0	3		7
9/5/01	1	0		0	5		6
9/7/01	4	0		6	7		17
9/10/01	4	0	(1)	0	2	(1)	6
9/11/01	0	2		0	1		3
9/12/01	1	3		0	0		4
9/14/01	2	0	(3)	0	0	(3)	2
9/17/01	8	4		1	3		16
9/18/01	2	8		0	0		10
9/19/01	6	8	(1,4)	0	0	(1,4)	14

(1) Chair side traps were changed.
(2) No dentist was in office; it was not a normal operating day. However, a sample was collected. The normal procedure was to accumulate sample volume over non operating days and collect it at the end of operating days.
(3) Line was flushed with 500 mL of PureVac flushing solution.
(4) Lines were flushed with 1000 mL of PureVac at the end of the characterization period, followed by a 1000 mL flush with clean water.

Entire period 7/10-9/20/02 Surfaces = 334 Operating Days = 42 Ave. surfaces / day = 7.95
Period 7/30-9/20/01 Surfaces = 232 Operating Days = 30 Ave. surfaces / day = 7.73
Data summaries do not include 8/6 and 8/23 as these were non-dentist days – i.e. no dentist was in the office. Under normal procedures, samples were only collected on normal business days when the dentist was in the office working.

Each wastewater sample resulted in three mercury concentration values, total mercury in the settleable solids, total mercury in the liquid fraction, and soluble mercury in the liquid fraction. All data tables report the settleable solids mercury concentration as "mercury from solids" and the liquid fraction mercury concentration as "total mercury liquid" and "soluble mercury liquid". It is important to remember the definition of these various fractions when comparing the results to other studies and when performing the calculations for total mass of mercury discharged or present in an untreated wastewater. A direct discharge of this type of wastewater would contain the mercury present in the settleable solids and the total mercury present in the liquid fraction. The total mercury concentration in the untreated wastewater would be the sum of the mass of mercury in the settled solids added to the mass of mercury (from the total mercury analysis sample) in the liquid volume divided by the total volume discharged.

$$\text{Total mercury conc.} = \frac{(\text{conc. in solids} \times \text{mass of solids}) + (\text{conc. in liquid} \times \text{vol. of liquid})}{\text{Total volume of sample}} \quad \text{(Eq. 1)}$$

Table 4-2 shows the settleable solids data, including the concentration of mercury in the solids and the total dry weight of the settled solids, which are the basis used for calculating the total mass of mercury in the settled solids. These results are from the collection and analysis of settleable solids using the settling procedure described in Appendix C and Section 3.1.3. Table 4-3 shows the mercury results for the liquid fraction (after removal of the settleable solids fraction), including both the total mercury in the liquid and the soluble portion (after filtration through a 0.45 micron filter). Table 4-3 also shows the volume of wastewater collected (total daily flow through the vacuum system), the calculated mass of mercury in the liquid and settled solids fraction, the calculated total mass of mercury in the discharge (settleable plus liquid fraction) and calculated total mercury concentration. The total mercury concentration is calculated by adding the mass of mercury in the solids and the liquid to calculate the total mass of mercury in the sample, and then dividing by the total wastewater (sample) volume for that day. The total mass of mercury in the office wastewater is shown graphically in Figure 4-1.

During the preparation and handling of the wastewater samples, it was necessary to use rinse water at several steps to ensure transfer of all of the solids and the mercury to the sample containers. All rinse water volumes were measured by weighing the rinse water bottle before and after each use. All of the rinse water dilutions were accounted for and the laboratory-measured concentrations were adjusted for these dilutions. The calculations and data used for these adjustments are presented in Appendix D.

The average total mercury concentration (settleable solids plus liquid) was 657 µg/L with the concentration varying from a high of 1810 µg/L to a low of 73 µg/L. The average mass of mercury in the wastewater was 1.60 mg/day varying from 0.05 mg/day to 6.81 mg/day. The liquid fraction (after settling) averaged 192 µg/L. The soluble mercury portion in the decant liquid averaged 127 µg/L, and typically represented 50-70 percent of the mercury in the liquid fraction of the wastewater. The summary statistics for the wastewater characterization are presented in Tables 4-4 and 4-5.

Table 4-2. Settleable Solids Results – Characterization Study

	Settleable Solids Fraction			Liquid Fraction
Date	Hg Conc. Dry Wt. mg/kg (A)	Mass of Dry Solids mg (B)	Mass of Hg in Sample mg (A*B)	Mass of Solids after Settling mg
7/10/01	220	274	0.0603	36.8
7/11/01	300	169	0.0507	129
7/12/01	310	151	0.0469	85.7
7/13/01	350	197	0.0688	50
7/16/01	74	1580	0.117	74.5
7/17/01	520	73.7	0.0383	52.8
7/18/01	140	71.7	0.0100	38.5
7/20/01	330	377	0.124	77.2
7/23/01	890	98.6	0.0878	90.1
7/24/01	(1)	2220	(1)	244
7/25/01	(1)	1350	(1)	142
7/27/01	2300	125	0.287	78.7
7/30/01	4800	421	2.02	61.4
7/31/01	3700	114	0.421	40.7
8/1/01	2000	1740	3.48	193
8/3/01	2000	267	0.535	68.7
8/6/01	5300	20.6	0.109	14.4
8/7/01	1300	900	1.16	110
8/8/01	6200	292	1.81	195
8/9/01	<0.6	16.4	<0.0002	13.2
8/10/01	4200	170	0.713	45.9
8/13/01	3800	715	2.72	103
8/14/01	410	65.2	0.0267	62.4
08/15/01	2700	1160	3.14	95.3
8/17/01	410	184	0.0754	43
8/20/01	860	120	0.103	38.7
8/21/01	1000	2040	2.04	40.8
8/22/01	4100	1330	5.44	156
8/23/01	390	30.2	0.0118	47.7
8/24/01	1800	525	0.944	47.2
8/27/01	1100	267	0.293	253
8/28/01	250	695	0.174	106
8/29/01	270	210	0.0567	324
8/31/01	160	725	0.116	235
9/4/01	1100	203	0.223	43.2
9/5/01	910	97.1	0.088	57.3
9/7/01	1100	939	1.03	20.2
9/10/01	2300	162	0.373	14.4
9/11/01	180	222	0.0400	45
9/12/01	740	259	0.192	89.2
9/14/01	2100	825	1.73	207.0
9/17/01	2100	862	1.81	25.7
9/21/01a(2)	7000	2280	15.9	184
9/21/01b(2)	4200	1550	6.49	0.4

(1) Lab sample was not analyzed.

(2) The “a” sample was collected after three days of office operation (9/18, 9/19, and 9/20) and included a flush with PureVac solution. The “b” sample was collected from a fresh water flush of the system immediately after the “a” sample was collected.

Table 4-3. Mercury Results – Characterization Study

	Liquid Fraction Data Sample Decanted after Settling Procedure					Settleable Solids		
Date	Final Conc. Liquid Total Hg	Final Conc. Liquid Soluble Hg	Soluble Hg	Total Discharge Volume Delivered	Mass of Hg From Liquid	Mass (1) of Hg From Settleable Solids	Total Mass Hg Liquid Fraction and Settleable Solids	Total Hg Discharged Total Mass divided by Total Volume
	(mg/L)	(mg/L)	(% Of Total)	(mL)	(mg)	(mg)	(mg/day)	(㎎/L) (ppb)
7/10/01	0.124	0.0080	6.5	874	0.111	0.0603	0.171	191
7/11/01	0.109	0.0994	91.4	2160	0.238	0.0507	0.289	132
7/12/01	0.113	0.0772	68.4	704	0.0840	0.0469	0.131	176
7/13/01	0.220	0.183	83.4	1630	0.367	0.0688	0.436	261
7/16/01	0.0634	0.0414	65.3	3160	0.204	0.117	0.321	99.7
7/17/01	0.209	0.118	56.4	930	0.203	0.0383	0.241	249
7/18/01	0.175	0.137	78.2	1420	0.251	0.0100	0.261	182
7/20/01	0.190	0.121	63.5	1350	0.262	0.124	0.387	280
7/23/01	0.253	0.187	74.1	1640	0.425	0.0878	0.512	305
7/24/01	0.0947	0.0678	71.5	3290	0.318			
7/25/01	0.231	0.114	49.4	5150	1.19			
7/27/01	0.345	0.164	47.6	1390	0.479	0.287	0.766	550
7/30/01	0.514	0.632	123	1650	0.850	2.02	2.87	1740
7/31/01	0.435	0.343	79.0	585	0.254	0.421	0.676	1150
8/1/01	0.136	0.113	83.4	3430	0.466	3.48	3.95	1150
8/3/01	0.0546	0.0048	8.8	1220	0.0664	0.535	0.601	494
8/6/01	0.0446	0.0236	52.9	210	0.0094	0.109	0.119	565
8/7/01	0.0984	0.0504	51.2	2560	0.252	1.16	1.42	553
8/8/01	0.149	0.0963	64.6	3600	0.536	1.81	2.34	651
8/9/01	0.416	0.385	92.5	129	0.0537	0.0000	0.0537	416
8/10/01	0.676	0.513	75.9	654	0.442	0.713	1.16	1770
8/13/01	0.526	0.394	75.0	2910	1.53	2.72	4.24	1460
8/14/01	0.510	0.364	71.2	700	0.366	0.0267	0.392	497
8/15/01	0.318	0.196	61.7	2100	0.667	3.14	3.80	1810
8/17/01	0.161	0.0771	47.8	634	0.102	0.0754	0.178	280
8/20/01	0.229	0.154	67.2	1120	0.255	0.103	0.358	321
8/21/01	0.083	0.0392	47.4	3960	0.328	2.04	2.37	599
8/22/01	0.139	0.0657	47.2	4690	0.653	5.44	6.09	1300
8/23/01	0.198	0.143	72.1	273	0.0544	0.0118	0.0662	241
8/24/01	0.213	0.164	77.1	1520	0.324	0.944	1.27	835
8/27/01	0.149	0.0703	47.1	2290	0.341	0.293	0.634	278
8/28/01	0.104	0.0159	15.3	2230	0.232	0.174	0.406	182
8/29/01	0.184	0.102	55.6	1270	0.379	0.0567	0.436	211
8/31/01	0.122	0.0251	20.5	2700	0.320	0.116	0.446	165
9/4/01	0.0574	0.0097	16.9	2030	0.126	0.223	0.349	160
9/5/01	0.0599	0.0235	39.2	1360	0.0812	0.0884	0.170	125
9/7/01	0.0578	0.0417	72.1	5880	0.340	1.03	1.37	234
9/10/01	0.0514	0.0408	79.4	1300	0.0829	0.373	0.456	283
9/11/01	0.0461	0.0044	9.5	1510	0.0784	0.0400	0.118	69.6
9/12/01	0.141	0.119	84.6	3040	0.428	0.192	0.619	204
9/14/01	0.378	0.0979	25.9	5040	1.90	1.73	3.64	722
9/17/01	0.215	0.140	65.0	2320	0.499	1.81	2.31	996
9/18/01	0.0547	0.0126	23.0	3090	0.169	5.31	5.48	1770
9/19/01	0.0547	0.0126	23.0	3090	0.169	5.31	5.48	1770
9/20/01	0.0547	0.0126	23.0	3090	0.169	5.31	5.48	1770
9/21/01b	0.0745	0.0393	52.8	4380	0.326	6.49	6.82	1560

9/18-9/20 – One sample was taken over three-day period.
9/21/01 – Cleaning solution included at the end of the third day – system was flushed.
9/21/01 – Represents water flush at the end of the characterization period to clear the lines before the verification test.
See Table 4-4 for summary statistics of this data.
(1) Data in this column were taken from Table 4-2, second column from the right.

Figure 4-1. Mass of Mercury in Office Wastewater – Characterization Test

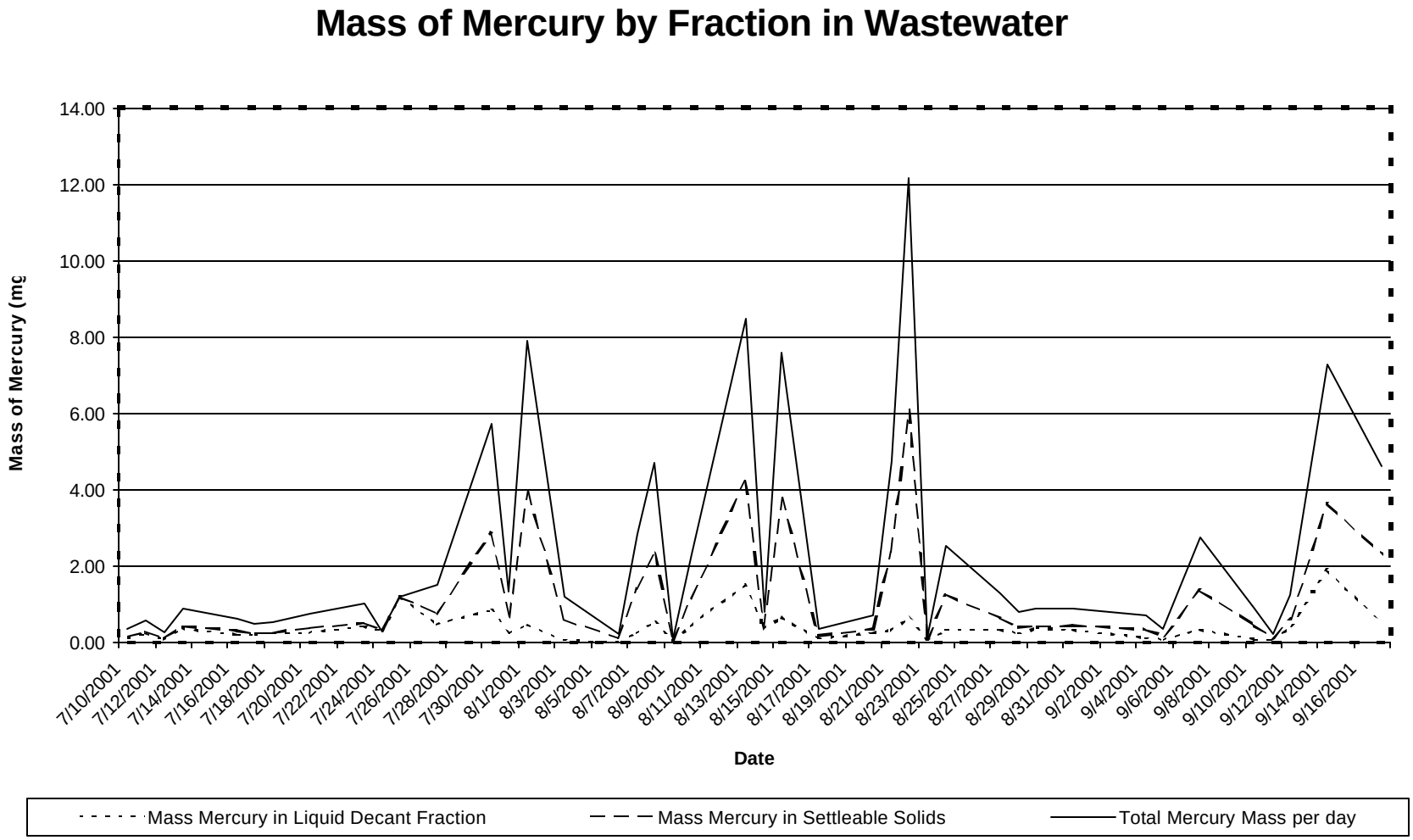


Table 4-4. Summary Statistics for Mercury – Characterization Study

	Decant Liquid Concentration (mg/L)		% of Total	Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble			Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Number	46	46	46	46	32	32	32	32.0
Average	0.192	0.127	66.1	2180	1.23	0.364	657	1.60
Maximum	0.676	0.632	93.5	5880	6.49	1.90	1810	6.82
Minimum	0.0446	0.0044	9.9	129	<0.01	0.0094	72.6	0.0537
Std. Dev	0.152	0.139	91.4	1410	1.81	0.369	581	1.94
Total mass				100,000	54.2 (mg)	16.7 (mg)		

Table 4-5. Summary Statistics for Mercury in Settleable Solids – Characterization Study

	Hg Conc. Dry Wt	Mass of Dry Solids	Mass of Hg in Sample
	mg/kg	mg	mg
Daily Ave	1680	567	1.23
Maximum	7000	2280	6.49
Minimum	74	6.4	<0.01
Std Dev	1831	641	1.81

The Protocol calls for the collection of a minimum of 25 samples over a minimum five-week period, and requires that a minimum of 40 amalgam surfaces per week be removed/placed. The VTP was designed to meet these minimums by adjusting the sample duration to account for the four-day operating week for this dental office. The actual duration of the characterization testing was eleven weeks. Samples were collected representing 44 days for two reasons. First, the number of surfaces that were being removed/placed during the first weeks of testing was below the 200 surfaces (five weeks x 40 surfaces per week = 200 surfaces), the targeted minimum. The additional samples provided data that met the minimum surface requirement for the protocol. Second, during the first three weeks of sampling, some adjustments needed to be made to the sample handling and settling procedures and the analyses to ensure that all needed data were being collected. In addition, two settled solids samples were not analyzed by the laboratory because of miscommunication. In order to ensure a complete data set for the characterization, the sampling was continued for the extended period. Once the data were complete, the subset of data from the July 30 - Sept 20 period that met the basic minimum requirement and the entire dataset for the period July 10 - Sept 20 were compared and found to be very similar in concentration and total mass loadings. Section 4.10.2 presents these comparisons and more information regarding this data.

The settleable solids fraction represented the largest portion of the mercury in the wastewater, accounting for 77 percent of the total mercury mass. While removing this fraction will reduce the mercury loading, the liquid portion still contained an average of 192 µg/L of mercury, which is well above the typical discharge limits allowed to lakes and rivers, and would be a source of mercury in wastewater treatment facilities receiving this wastewater.

4.3 pH Results – Characterization Study

Samples were monitored for pH as they arrived at the laboratory. The pH normally ranged from 7 to 9 over the characterization period, as shown in Table 4-6. The pH was lower when the vacuum lines were flushed with cleaning solution, but not all low values corresponded to the days on which flushing occurred.

4.4 Installation and Startup of DRNA MRU

The characterization phase of the test was completed on September 21, 2001. After the lines were flushed and the last sample was collected, the DRNA MRU was installed in the vacuum system in preparation for the start of the verification test. The MRU inlet line to the solids separator was attached to the vacuum system at the location where the characterization sample bottle had been installed. The outlet air from the MRU was attached to the vacuum line that had been attached to the exit air fitting of the sample bottle during the characterization phase and was just upstream of the existing air/water separator. Installation of these lines was straightforward and took only a few minutes. See Figure 3-1.

The water discharge line of the BullfroHg separator was connected to the tubing pump on the MRU. The adsorption system inlet line was attached to the outlet of the pump and the discharge line from the MRU placed in a clean sample bottle. The entire hookup time was less than one hour. Once the system was setup, it was wet tested by adding water to the separator. The manual operation button was pushed and the pump moved clean water from the separator through the adsorption column and into the sample container. All fittings were checked and there were no leaks. The low level sensor in the BullFroHg separator shutdown the pump when the water in the separator reached the low level shutoff point. The pump timer was set at the factory to turn on at 3 a.m., which allows sufficient time for all of the settled wastewater accumulated during the normal business day to be pumped through the adsorbent filter before the start of the business at 7:30 a.m. in the morning.

The installation and setup went quickly (less than 3 hours with the wet test included) and only required normal tools. Once the unit was setup, it was ready to operate on Monday morning, September 24, 2001, when the dental office opened. The installation and startup procedures, included in the operation and maintenance manual in Appendix A, were followed as written for this test. The instructions were easy to read and follow.

Table 4-6. pH Results – Characterization Study

Date	pH (SU)	Date	pH (SU)
7/9/01	3.72	8/14/01	8.91
7/10/01	8.39	08/15/01	8.9
7/11/01	8.93	8/17/01	7.96
7/12/01	9.04	8/20/01	7.53
7/13/01	8.96	8/21/01	6.94
7/16/01	7.01	8/22/01	8.28
7/17/01	8.82	8/23/01	8.6
7/18/01	9.21	8/24/01	8.94
7/20/01	8.9	8/27/01	8.25
7/23/01	8.86	8/28/01	8.57
7/24/01	8.55	8/29/01	7.45
7/25/01	7.96	8/31/01	8.72
7/27/01	6.35	9/4/01	6.07
7/30/01	9.01	9/5/01	6.53
7/31/01	9.17	9/7/01	3.24
8/1/01	8.88	9/10/01	3.57
8/3/01	8.95	9/11/01	7.07
8/6/01	6.88	9/12/01	8.62
8/7/01	7.53	9/14/01	6.82
8/8/01	6.95	9/17/01	5.27
8/9/01	8.73	9/21/01(a)	6.5
8/10/01	8.87	9/21/01(b)	2.89
8/13/02	8.4		

Note: The "9/21/01a" sample was after three days of office operation and included a flush with PureVac solution. The "9/21/01b" sample was collected from a fresh water flush of the system immediately after the "a" sample was collected.

4.5 Verification Test

The verification test started on September 24, 2001 and concluded on November 8, 2001. A total of 32 samples of MRU treated effluent were collected and analyzed in accordance with the VTP Procedures. During the seven-week verification period, the dental office added a dentist on a part time basis, and the office operated on a four or five day per week schedule. On three of the sampling days, the dentists were not in and only hygiene activities were performed.

Sample collection time during the verification test was in the morning whereas the characterization test samples were collected at the end of each business day. The wastewater generated during a normal day was treated in the MRU overnight (settling of solids and subsequent pumping of the decant liquid through the adsorbent). Therefore, each day's sample was not available until the next morning. Samples were collected each business day in the morning and represent the previous day's wastewater flow.

4.6 Mercury Amalgams Removed and Placed

Records of the number of mercury amalgam surfaces removed and placed, along with the associated tooth number, were maintained during the verification test in the same manner as described for the characterization test. During the verification test, 243 surfaces were removed or placed on 29 operating days giving an average of 8.38 surfaces placed or removed per operating day. This rate of removal and/or placement was similar to the rate during the characterization test (7.73 – 7.95 surfaces per day).

The number of surfaces placed or removed by day is shown in Table 4-7. The addition of a second part time dentist resulted in three operatory rooms at the office being used for amalgam procedures.

The dental technician logs also showed the days when flushing of the lines occurred using the PureVac cleaning solution. Table 4-7 shows the days when line flushing occurred and the quantities of cleaning solution used during the verification test. Chair side traps were also changed several times during the verification test period and are noted in Table 4-7.

Table 4-7. Summary of Number of Surfaces Removed and Placed – Verification Test

Date	Room 1			Room 2			Room 3			Total Surfaces
	Surfaces Removed	Surfaces Placed	Notes	Surfaces Removed	Surfaces Placed	Notes	Surfaces Removed	Surfaces Placed	Notes	
9/25/01	0	0		4	1		0	0		5
9/26/01	4	5		3	1		0	0		13
9/27/01	0	0	(1,4)	3	3	(1,4)	0	0	(1,4)	6
9/28/01	0	0	(2)	0	0	(2)	0	0	(2)	0
10/1/01	6	0		0	0		0	0		6
10/2/01	4	0		4	10		0	0		18
10/3/01	2	2		0	0		0	0		4
10/4/01	3	0	(3)	3	0		4	4		14
10/5/01	7	7	(1,3)	2	0	(1,3)	0	0	(1,3)	16
10/8/01	0	0	(3)	3	2		0	0		5

Table 4-7. (continued) Summary of Number of Surfaces Removed and Placed – Verification Test

Date	Room 1			Room 2			Room 3			Total Surfaces
	Surfaces Removed	Surfaces Placed	Notes	Surfaces Removed	Surfaces Placed	Notes	Surfaces Removed	Surfaces Placed	Notes	
10/9/01	0	0		6	4		6	0		16
10/10/01	1	0		0	1		0	0		2
10/11/01	2	2		0	0		16	0		20
10/12/01	1	0	(1,3)	7	0	(1)	0	0	(1)	8
10/15/01	3	0		2	0		0	0		5
10/16/01	2	0	(3)	4	5		0	0		11
10/17/01	0	0	(2)	0	0	(2)	0	0	(2)	0
10/18/01	0	0	(1,3)	0	1	(1,3)	5	0	(1,3)	6
10/19/01	0	0	(2)	0	0	(2)	0	0	(2)	0
10/22/01	0	1		4	4		0	0		9
10/23/01	0	0		1	0		0	0		1
10/24/01	0	3		0	4		0	0		7
10/25/01	4	0	(1,3)	0	0	(1,3)	2	1	(1)	7
10/26/01	0	0	(2)	0	0	(2)	0	0	(2)	0
10/29/01	0	2		0	2		0	0		4
10/30/01	5	2		1	0		0	0		8
10/31/01	0	0		2	2		3	0		7
11/1/01	0	0		0	0		2	0		2
11/2/01	0	0	(1,3)	1	2	(1,3)	0	0	(1)	3
11/5/01	0	0		6	2		0	0		8
11/06/01	0	0		3	4		0	0		7
11/07/01	8	6		3	0		0	0		17
11/08/01	2	0	(5)	3	3	(5)	0	0	(5)	8

(1) Chair side traps were changed.
(2) No dentist was in office; it was not a normal operating day. However, a sample was collected. The normal procedure was to accumulate sample volume over non operating days and collect it at the end of operating days
(3) Line was flushed with 500 mL of Pure Vac flushing solution.
(4) Line was flushed with 1000 mL of Pure Vac flushing solution
(5) Lines were flushed with 1000 mL of Pure Vac at the end of the verification period, followed by a 1000 mL flush with clean water.

Total surfaces = 243 Total Days = 33 Operating Days = 29 Ave. surfaces/day = 8.38

4.7 Mercury Results – Verification Test

The entire wastewater flow was treated in the MRU, and the entire discharge from the MRU was collected in the treated wastewater sample bottle in the same manner as for the characterization test. The treated water sample did not contain the settleable solids trapped in the BullfroHg, as these were retained in the separator until the end of the verification testing. The samples were delivered to the laboratory and the settleable solids separation procedure was performed to generate both a liquid decant fraction and a settleable solids fraction for analysis. All procedures used in the characterization phase, as described in Sections 4.2 and 3.3.3.1, were followed for the verification test samples.

The results for the mercury analyses of the treated water are shown in Table 4-8. As described in Section 4.2, these results are based on the laboratory analytical data with adjustments made for the various volumes of rinse water used during the sample handling and preparation procedures. The summary laboratory data and the various calculations are included in Appendix D. The calculations described in Section 4.3 were used to combine the settleable solids data and the liquid data to determine the final mass and concentration of total mercury in the treated water, which would normally be discharged to the sewer system. The mercury concentrations measured in the settleable solids samples and the dry weights of the settled solids present in the discharge are shown in Table 4-9, and graphically in Figure 4-2.

The mercury concentrations measured in the liquid fraction were below the detection limit (0.2 µg/L) for several days and there were no settleable solids present in the sample on four (4) days. These results require an approach be used to account for "less than values" when determining average concentrations and developing other statistical data. Two approaches that have been used by USEPA and others is to assume that values below the detection limit are equal to either zero or one half (1/2) the detection limit. Both approaches have been used to analyze this data. The summary statistics shown in Table 4-10 present the results using both approaches. The data show that the differences between the two methods are very small for this data set, yielding an average total mercury concentration in the effluent of 10.3 µg/L as shown in Table 4-10 (a) (using zero for "<" values) and 10.4 µg/L as shown in Table 4-10 (b) (using ½ the detection limit for "<" values). Based on the similarity of the results, all discussions and comparisons presented will be based on assuming values below the detection limit are equal to zero.

The average discharge concentration of total mercury was 10.3 µg/L with a maximum of 39.8 µg/L and a minimum of <0.2 µg/L. The average mass of mercury discharged on a daily basis was 0.036 mg/day, with the settleable solids portion representing an average of 0.007 mg/day and the liquid fraction having an average of 0.0284 mg/day. The mercury contribution from the settleable solids thus represented 19 percent of the mercury present in the discharge versus 77 percent in the untreated wastewater. Tables 4-10 and 4-11 show these summary statistics. Clearly, the solids separator was retaining settleable solids and the mercury content of these solids. The overall discharge level of mercury is significantly below the levels measured during the untreated wastewater characterization test, indicating the DRNA MRU was removing a significant amount of the mercury present in the wastewater. A detailed comparison of the results and calculations of the removal percentages is discussed in Section 4.10.

The mercury concentration in the discharge was either below the detection limit (<0.2 µg/L) or in the 0.2 to 3.5 µg/L range for the first eighteen days of the verification test. During the first few days, the effluent had no settleable solids and had very low solids suspended in the liquid. As the test progressed, the effluent began to darken in color and became very black with noticeable suspended particulate present. Only a small portion of these solids settled during the settling procedure in the laboratory. The amount of solids being filtered from the liquid fraction began to increase and the solids were very black and fine in appearance. DRNA was contacted and their technical department suspected that the bleach concentration being used to keep the adsorbent clear of organic interference was causing the carbon in the column to breakdown and pass through the final filter. DRNA had recently changed the recommended bleach concentration in the feed solution from one part bleach to one part water to a new ratio of one part bleach to two parts water. On October 17, the bleach solution was changed to the new recommended strength. Between October 17 and October 25, the total mercury concentration in the effluent, the mass of settleable solids found in the separation procedure, and the amount of solids being filtered from the decant liquid reached peak values, as shown in Tables 4-8 and 4-9 and Figure 4-2. After October 25, the mass of dry solids and the mercury concentration stabilized and began to decrease. Levels of mercury in the discharge continued to decrease until the last two days of the verification test. On the last two days, the mass and concentration of mercury present in effluent increased to levels similar to those measured earlier in the verification period. Both days had higher flows, which may have impacted the removal of mercury. The higher flow on the last day was due to the extra flushing of the system that was performed in order to clear the vacuum lines. The system was flushed with one quart of PureVac and one quart of water at each chair in order to remove as much mercury as possible from the vacuum system. The previous day's flow (November 7) may have be due to the larger than average number of mercury amalgam surface removals and placements that were performed, although the overall dataset did not seem to substantiate a correlation between amalgam surface removals and/or placements with total flow.

The results clearly indicate that the MRU performed well in the first half of the verification test period. Mercury levels were significantly reduced in the second half of the test, however the performance was impacted by the condition of the adsorbent column. According to DRNA, the problem with the bleach attacking the carbon has not been a widespread problem and they changed their bleach solution concentration to resolve this type of problem. While the issue of carbon breakdown and the presence of small particulate in the effluent stabilized in the later part of the verification test, the discharge levels remained significantly above the levels measured at the beginning of the test. These data indicate that once the column is attacked the process cannot be reversed in a short period.

Table 4-8. Mercury Results - Verification Test

Liquid Fraction Data Sample Decanted after Settling Procedure						Settleable Solids		
Date	Final Conc. Total Hg	Final Conc. Soluble Hg	Soluble Hg	Total Volume Discharged	Mass of Hg from Liquid	Mass of Hg From Solids	Total Mass Hg	Total Hg Discharged
	mg/L	mg/L	% of Total	mL	mg	mg	mg/day	µg/L (ppb)
9/25/01	<0.0002	<0.0002		1250	<0.0003	0	<0.0003	<0.2
9/26/01	0.0003	0.0004	133	2240	0.0007	0	0.0007	0.3
9/27/01	<0.0002	<0.0002		327	<0.0001	0	<0.0001	<0.2
9/28/01	<0.0002	<0.0002		1350	<0.0003	0.0005	<0.0003	<0.4
10/1/01	0.0029	0.0025	86.2	623	0.0018	0.0004	0.0022	3.5
10/2/01	0.0005	<0.0002		2850	0.0014	0.0054	0.0040	1.4
10/3/01	<0.0002	<0.0002		1080	<0.0002	0.0009	<0.0004	<0.8
10/4/01	0.0007	0.0004	69.1	2270	0.0068	0.0005	0.0073	3.2
10/5/01	<0.0002	<0.0002		177	<0.0001	0.0001	<0.0003	<0.6
10/8/01	0.0017	0.0006	35.3	5660	0.0096	0.0096	0.0192	3.4
10/9/01	0.0007	0.0002	28.6	4740	0.0033	0.0020	0.0053	1.1
10/10/01	0.0003	<0.0002		2850	0.0011	0.0013	0.0024	0.8
10/11/01	0.0004	0.0003	75.0	1440	0.0006	0.0005	0.0011	0.8
10/12/01	0.0006	0.0007	117	1280	0.0008	0.0010	0.0018	1.4
10/15/01	0.0006	0.0004	66.7	3770	0.0023	0.0048	0.0071	1.9
10/16/01	0.0006	0.0006	100	1440	0.0009	0.0013	0.0022	1.5
10/17/01	0.0011	0.0006	54.5	4280	0.0047	0.0074	0.0121	2.8
10/18/01	0.0023	0.0012	52.2	319	0.0007	0	0.0007	2.2
10/22/01	0.0057	0.0014	24.6	660	0.0038	0.0052	0.0090	13.6
10/23/01	0.0293	0.0051	17.4	5940	0.174	0.0429	0.217	36.5
10/24/01	0.0322	0.0085	26.4	4120	0.133	0.0148	0.148	35.8
10/25/01	0.0337	0.0115	34.1	1320	0.0445	0.0081	0.0526	39.8
10/26/01	0.0172	0.0049	28.5	2440	0.0420	0.0060	0.0480	19.7
10/29/01	0.0154	0.0038	24.7	3330	0.0513	0.0120	0.0633	19.0
10/30/01	0.0086	0.0023	26.7	4430	0.0381	0.0144	0.0525	11.9
10/31/01	0.0108	0.0029	26.9	1720	0.0186	0.0185	0.0371	21.5
11/1/01	0.0083	0.0026	31.3	1340	0.0111	0.0065	0.0176	13.2
11/2/01	0.0085	0.0008	9.4	1250	0.0106	0.0051	0.0157	12.5
11/5/01	0.0078	0.0038	48.7	3870	0.0302	0.0056	0.0358	9.3
11/7/01	0.0089	0.0056	62.9	1940	0.0172	0.0004	0.0176	9.1
11/8/01	0.0212	0.0135	63.7	6060	0.129	0.0250	0.154	25.3
11/9/01	0.0331	0.0118	35.6	5340	0.177	0.0338	0.211	39.4

Table 4-9. DRNA MRU Settleable Solids Results

Date	Settleable Solids Fraction			Liquid Fraction
	Hg Conc. Dry Wt. (mg/kg)	Mass of Dry Solids (mg)	Mass of Hg in Sample (mg)	Mass of Solids after Settling (mg)
	(A)	(B)	(A*B)	
9/25/01	<1	0	0	4.4
9/26/01	<1	0	0	5
9/27/01	<1	0	0	7.1
9/28/01	12	39.4	0.0005	30.8
10/1/01	24	15.8	0.0004	18.9
10/2/01	21	258	0.0054	38.7
10/3/01	21	43.1	0.0009	21.4
10/4/01	5	106	0.0005	35.4
10/5/01	7.5	8.2	0.0001	6.3
10/8/01	8	1210	0.0096	74.9
10/09/01	4	490	0.0020	40.5
10/10/01	9	149	0.0013	19.5
10/11/01	8	66	0.0005	46.1
10/12/01	9	111	0.0010	132
10/15/01	3	1610	0.0048	21.1
10/16/01	6	209	0.0013	18
10/17/01	3	2460	0.0074	78.7
10/18/01	<1	0	0	205
10/22/01	28	187	0.0052	
10/23/01	76	564	0.0429	146
10/24/01	75	197	0.0148	114
10/25/01	36	224	0.0081	85.7
10/26/01	50	120	0.0060	67.9
10/29/01	48	249	0.0120	81.2
10/30/01	49	293	0.0144	104
10/31/01	37	501	0.0185	96.9
11/1/01	31	211	0.0065	78.6
11/2/01	26	198	0.0051	131
11/5/01	46	121	0.0056	62.7
11/7/01	17	22	0.0004	35.9
11/8/01	160	156	0.0250	32.6
11/9/01	210	161	0.0338	46.7

Bleach concentration changed on October 17, 2001

Figure 4-2. Mass of Mercury Discharged from MRU

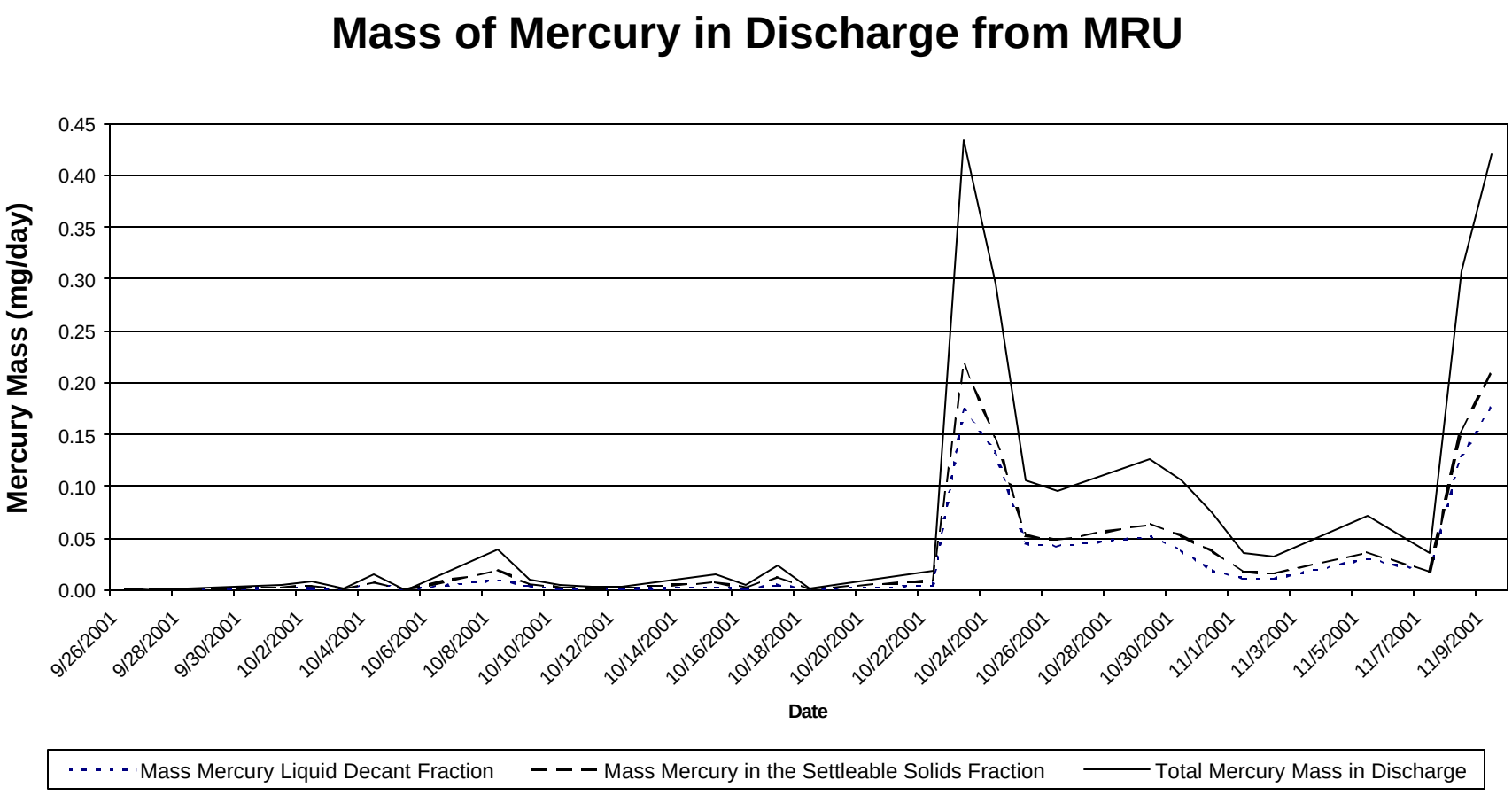


Table 4-10. Summary Statistics Mercury Results for DRNA MRU Effluent

(a) **All Values Below Detection Limit set equal to zero in calculations**

	Decant Liquid Concentration (mg/L)		% of Total	Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble			Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Number	32	32	25	32	32	32	32	32.0
Average	0.0079	0.0027	66	2550	0.0073	0.0284	10.3	0.0357
Maximum	0.0337	0.0135	100	6060	0.043	0.177	39.8	0.217
Minimum	<0.0002	<0.0002	9.4	177	0.00	<0.0002	<0.2	<0.0003
Std. Dev	0.0108	0.0037	N/A	1770	0.0103	0.0507	12.8	0.0601
Total mass				81,700	0.234 (mg)	0.909 (mg)		

(b) **All Values Below Detection Limit set equal to ½ the detection limit in calculations**

	Decant Liquid Concentration (mg/L)		% of Total	Total Wastewater Volume (mL)	Hg Mass (mg/day)		Total Wastewater	
	Total	Soluble			Settleable Solids	Decant Liquid	Concentration (µg/L)	Mass (mg/day)
Number	32	32	25	32	32	32	32	32
Average	0.0079	0.0027	66	2550	0.0073	0.0284	10.4	0.0357
Maximum	0.0337	0.0135	100	6060	0.0429	0.177	39.8	0.217
Minimum	0.0001	0.0001	9.6	177	0.00	<0.0001	0.100	<0.0001
Stand Dev	0.0108	0.0037	N/A	1770	0.0102	0.051	12.8	0.0599
Total mass				81,700	0.234 (mg)	0.909 (mg)		

Table 4-11. Summary Statistics Settleable Solids Results for DRNA MRU Effluent

	Settleable Solids Fraction			Liquid Fraction
	Hg Conc. Dry Wt	Mass of Dry Solids	Mass of Hg in Sample	Mass of Solids after settling
	mg/kg	mg	mg	mg
Average	32.2	312	0.007	58.9
Maximum	210	2460	0.043	205
Minimum	0.00	0.00	0.000	4.40
Std Dev	45.7	521	0.010	48.9

4.8 pH Results Verification Study

The pH was measured for each treated wastewater sample when it arrived at the laboratory. Table 4-12 shows the pH results for the verification test period. As shown in the table, the pH was very stable in the discharge from the MRU. The changes in pH noted in the characterization test (Table 4-6) were dampened by the treatment process. The range of pH for the test period was 6.42 to 7.48.

Table 4-12. pH Results Verification Test

Date	pH (SU)	Date	pH (SU)
9/25/01	6.87	10/18/01	7.27
9/26/01	6.71	10/19/01	7.18
9/27/01	6.69	10/22/01	7.26
9/28/01	6.75	10/23/01	7
10/1/01	6.75	10/24/01	7.21
10/2/01	7	10/25/01	7.38
10/3/01	6.96	10/26/01	7.35
10/4/01	7.05	10/29/01	7.56
10/5/01	7.11	10/30/01	7.27
10/8/01	6.84	10/31/01	7.24
10/9/01	6.7	11/1/01	7.33
10/10/01	6.5	11/2/01	7.24
10/11/01	6.42	11/5/01	7.32
10/12/01	n/a	11/7/01	7.24
10/15/01	6.68	11/8/01	7.48
10/16/01	7.08	11/9/01	7.38
10/17/01	7.09		

n/a – not analyzed

4.9 Residue Results for DRNA MRU

At the end of the verification test, the MRU was taken to the laboratory to be disassembled and the residues sampled for mercury content. Section 3.3.3.2 describes the residue sample collection and processing procedure. Collection and analysis of the residues was critical to the verification test as it provided data for determining the actual amount of mercury removed and retained during the verification test.

The results of the residue analysis are presented in Table 4-13. The separator solids represent the solids settled in the BullFroHg separator during the test. A total of 44.8 grams of solids was collected over the verification test period. These solids showed an average total mercury concentration of 4050 mg/kg. The six samples showed a range of concentration from 3800 to 4400 mg/kg, which indicates that the solids sample was well mixed and consistent in concentration among the subsamples taken for analysis. The total mass of mercury collected over the 32-day period was 181.4 mg.

The original VTP included analysis of the settleable solids from the separator for leachable mercury using the USEPA TCLP. This analysis could not be performed, as the test requires a minimum of 200 grams of sample and only 44.8 grams were collected for the entire verification test period. TCLP is a test used to evaluate solid materials for hazardous waste classification and disposal. It is possible that the solids could leach mercury at levels that would classify this waste as hazardous. The total concentration of mercury is above the 260 mg/kg level designated by the USEPA as requiring mercury recovery under the Land Disposal Restrictions (LDR). Solids with high mercury concentrations must be sent for mercury reclamation. One of the services DRNA provides its customers is the return of the separator to them for mercury recycling. The other residuals, filter, carbon and resin are also returned to DRNA for mercury recycling as part of the DRNA services.

The particle filter weighed 83.2 grams after drying. The original weight of the filter is not known so the actual amount of solids retained by the filter (solids, carbon, and resin) cannot be determined. The filter did show that it was impregnated with a large amount of small black particles, similar to the carbon material present in the adsorption column and similar to the particles that were present in the effluent in the second half of the test. The average mercury concentration in the filter samples (filter media plus retained solids) was 0.587 mg/kg and the calculated mass of mercury on the filter was 0.049 mg. While the actual amount of retained solids cannot be determined, the total mass of mercury present is known and is not significant in the overall mass balance, representing less than 0.1 percent of the mercury in the residues.

The carbon remaining in the adsorption column was 126 grams (the starting weight is not known but DRNA indicated that 250-300 grams of carbon is typically charged to the column) with an average concentration of total mercury of 39.5 mg/kg. The total mass of mercury was 4.98 mg. The resin material weighed 1130 grams on a dry weight basis and showed an average concentration of 8.2 mg/kg. The resin contained a mass of 9.24 mg of mercury. These results show that mercury was being removed by both the carbon and the selective resin in the

adsorption column and serves as a basis for calculating the mercury loading to the adsorption column from the liquid fraction of the wastewater.

Table 4-13. Solid Residue Results – DRNA MRU

BullfroHg Collecte d Solids		**Particle Filter**	
	Total Dry Solids = 44.8 grams		Total Dry Solids = 83.2 grams
Sample	Hg Concentration mg/kg	Sample	Hg Concentration mg/kg
1	4300	1	0.93
2	3800	2	0.36
3	3800	3	0.47
4	4100		
5	3900		
6	4400		
Ave	4050	Ave	0.587
Max	4400	Max	0.93
Min	3800	Min	0.36
Std Dev	259	Std Dev	0.3
Total Hg	181 mg	Total Hg	0.049 mg

Carbon Solids		**Resin Solids**	
	Total Dry Solids = 126 grams		Total Dry Solids = 1132 grams
Sample	Hg Concentration mg/kg	Sample	Hg Concentration mg/kg
1	20	1	7.2
2	22	2	7.7
3	24	3	7.1
4	41	4	10
5	85	5	9
6	45	6	8
Ave	39.5	Ave	8.2
Max	85	Max	10
Min	20	Min	7.1
Std Dev	24.6	Std Dev	1.1
Total Hg	4.98 mg	Total Hg	9.24 mg

4.10 Performance of the DRNA MRU

4.10.1 Comparison Approach

The typical approach to measuring the performance of a wastewater treatment device is to monitor the influent and effluent during the verification test period and calculate the removal efficiency of the unit. However in designing the VTP, it was not possible to collect influent samples during the verification period due to the small size of the influent flow, the operation of the system under vacuum, and the difficulty of obtaining representative samples (particularly of solids) from small pipes, with small intermittent flow under vacuum. The VTP was designed to obtain data that could be used to follow two different approaches to determine the treatment efficiency of the unit.

In the first approach, the VTP included the characterization test to obtain data on the wastewater concentrations and masses, which could be used to determine the average mercury concentration and mass discharged from the dental office. If the dental office operation was similar during both the characterization period and the verification period, the characterization data could be used for comparison with the treated wastewater data.

The second approach was to collect and analyze all of the residuals from the treatment process so that the total mass of mercury retained by the unit during the verification test could be determined. The total mass measured in the discharge could then be compared to the total mass entering the unit (retained mercury plus discharged mercury) and the removal efficiency could be calculated. The calculation of the total load to the treatment unit could also be compared to the total mass of mercury measured in the characterization test to serve as a check that conditions were similar during both periods. The samples were also separated into the settleable solids fraction and decant liquid fraction to provide an additional method for comparing the characterization data with the treated water data. Both methods have been used in calculating the removal percentages given in this section.

4.10.2 Removal Efficiency Based on Characterization Data

The data presented in Tables 4-1 through 4-6 show the concentrations of mercury determined during the characterization test and the number of surfaces removed and placed during the test period. The characterization test covered a period of 42 operating days with a total of 334 amalgam surface removals and placements. The verification test occurred over 29 operating days during which 243 surfaces were removed and placed. In order to more closely match the characterization results with the verification test, a subset of the characterization data was also used for determining the total mercury and solids load. During the period July 30 through September 20, 2001, the last eight weeks of the characterization test, there were 30 operating days and 232 surfaces were removed or placed. Further, the total flow during July 30 to September 20 was 77 liters compared to 82 liters during the verification test. Thus, this period has very similar operating characteristics to the verification period. The Wilcoxon Signed Rank Test, a non-parametric statistic, was used to evaluate the two data sets and determine if they were statistically similar. The results of the test show that the two test periods (July 30 – September 20, and September 25 – November 9) were similar (not statistically different, Z= -0.518). A

comparison of the full characterization period data set with the verification data set showed that these data were also similar (not statistically different). Both tests were evaluated at the 95 percent confidence level. The results of the statistical evaluation are presented in Appendix D.

Table 4-14. Removal Efficiency Based on Characterization Data - Daily Averages

	Settleable Solids Mass (mg/day)	Decant Liquid Mass (mg/day)	Total Wastewater	
			Concentration (µg/L)	Mass (mg/day)
Characterization Data – 7/10-9/20/2002	1.23	0.36	657	1.60
Characterization Data – 7/30-9/20/2002	1.57	0.37	778	1.94
MRU Discharge (9/25-11/9/2002)	0.0073	0.0284	10.3	0.0357
% Removal –Compared to 7/10-9/20 Data	99.4	92.1	98.4	97.8
% Removal – compared to 7/30-9/20 Data	99.5	92.3	98.7	98.2

Table 4-15. Removal Efficiency Based on Characterization Data - Total Mass and Average Concentration

	Settleable Solids Mass (mg)	Decant Liquid Mass (mg)	Total Wastewater	
			Concentration (µg/L)	Mass (mg)
Characterization (7/30-9/20/2002)	53.3	12.7	778	66.0
MRU Discharge (9/25-11/9/2002)	0.234	0.909	10.3	1.14
% Removal	99.6	92.8	98.7	98.3

Tables 4-14 and 4-15 show the summary of these data and the calculated removal efficiencies attained by the DRNA MRU using the characterization data. The evaluation of removal efficiency using the two different databases gives very similar results. The data also show that the average mass loadings during the characterization test were very similar to the subset data from July 30 through September 20, 2001. While the load of mercury and solids varied considerably on a day-to-day basis, the averages of the data for these two data sets were very similar. The DRNA MRU was effective in removing the settleable solids and the mercury in these solids, and achieved better than 99 percent removal either on an average concentration basis or on a total mass basis. Overall removal of mercury (solids and liquid combined) was

between 98.4 and 98.7 percent on a concentration basis and 97.7 to 98.6 percent on a total mass basis. The MRU also was effective in removing the mercury associated with the liquid fraction (soluble and non settleable mercury), showing efficiencies in the 92.3 to 92.8 percent range.

4.10.3 Removal Efficiency Based on Verification Data Mass Balance

The data shown in Tables 4-8 through 4-11 and 4-13 show the mercury results, and the mass of mercury discharged from and retained in the MRU during the verification test. These data allow the calculation of the total mercury in the influent to the unit. All of the treated water effluent was monitored during the verification test and the mercury retained in the unit was measured at the end of the verification test. Table 4-16 shows the removal efficiency of the MRU based on the mass balance approach.

Table 4-16. Removal Efficiency based on Mass Balance of Retained and Discharged Mercury

	Mass of Mercury		
	Settleable Solids (mg)	Decant Liquid (mg)	Total Wastewater (mg)
Separator-Retained	181	-	181
Filter-Retained	-	0.049	0.049
Carbon-Retained	-	4.98	4.98
Resin-Retained	-	9.24	9.24
Discharge	0.234	0.909	1.14
Total Mass Load	182	15.2	197
% Removal	99.9	94.0	99.4

$$\%\text{Removal} = ((\text{Total} - \text{Discharge})/ \text{Total}) \times 100$$

Using the mass balance approach, the DRNA MRU removed more than 99 percent of the mercury in the settleable solids and more than 99 percent of the total mercury in the wastewater discharge. The MRU was also effective in reducing the mercury in the liquid fraction by 94 percent.

The removal efficiencies calculated by mass balance are similar to the removal efficiencies found using the characterization data. In general, the mass balance approach does tend to show somewhat greater removal efficiencies. This is because the total mass of mercury found during the verification test, particularly in the settleable solids, was higher in the verification test than during the characterization test. The mass of mercury in the liquid fraction during the characterization test was 12.9 mg and the mass of mercury in the liquid fraction during the verification test showed 15.0 mg. These quantities of mercury are very similar. The mass of mercury measured in the settleable solids fraction during the characterization test was 53.3 mg, whereas the settleable solids retained in the separator during the verification test showed a mass of mercury of 182 mg. The high efficiency shown by the MRU for retaining settleable solids and the larger contribution of the settleable solids to the total mercury mass in the discharge during the verification test, resulted in higher calculated removal efficiency for the MRU.

Overall, these comparisons show that the DRNA MRU can remove more than 99 percent of the mercury associated with settleable solids, 98-99 percent of the total mercury present in the wastewater, and from 92-94 percent of the mercury associated with the liquid fraction (soluble plus non-settleable particulate) of the wastewater.

4.11 MRU Operational Characteristics

During the verification test, qualitative and quantitative factors were observed or measured to help describe the operational characteristics of the DRNA MRU and the cost factors associated with operating and maintaining the unit.

4.11.1 Qualitative Factors

The MRU was very easy to operate, requiring virtually no operator intervention except for an occasional check that the pump was working, and replenishment of the bleach solution on a monthly basis. Once the unit was setup, there were no maintenance requirements and the unit ran without interruption for eight weeks. All indications are that the unit could easily operate several months without experiencing a mechanical problem (recommended maintenance interval is 6-12 months, except weekly checks of the bleach reservoir). Labor to operate the unit is minimal. If the unit is checked periodically (once per week) and bleach solution is added once per month, the total time to operate and maintain the unit would be less than 2-4 hours per month (½ to 1 hour per week).

The dental office vacuum system was not impacted by the MRU. The MRU easily attaches to the vacuum line before the air/water separator, which helps to minimize potential impact on the vacuum system. Once the system is installed, the only real impact the MRU could have on the system would be if there were a leak in one of the vacuum lines or if the BullFroHg separator lost the vacuum seal.

The entire unit is self contained and designed to eliminate operator contact with the untreated wastewater or the residuals. The treated effluent can be plumbed direct to the sewer system. The normal DRNA approach is for the dental office to return the used separator and adsorbent column and replace them with clean units. DRNA arranges for removal of the mercury and waste material from the MRU components at an appropriate facility. Based on the design, operational approach, and use of DRNA to handle the residual, the unit is considered a very safe unit from a health or waste contact perspective.

The Operations and Maintenance Manual is provided in Appendix A. Review of the manual and using it to install the MRU show that it is easy to read and follow. The instructions for installation are simple step-by-step instructions. Operational concepts explained in the technical section are easy to understand. The maintenance section uses text and tables to help explain the maintenance procedures required and the time interval for these activities.

The only operational problem encountered during the verification test was the increase in solids in the discharge. The apparent attack of the carbon by the bleach solution, causing the carbon to breakdown and be discharged, could be a major operational issue if it continued unnoticed or unabated. The discharge of the carbon fines reduced the removal efficiency. Carbon breakdown should have no impact on the settleable solids removal, the major source of mercury, as these solids are removed before the carbon unit and are completely separate from the adsorbent column. The liquid discharge showed degradation in mercury removal as fine particulate (apparently the carbon adsorbent) began to escape from the adsorbent column. If this breakdown of the carbon continued over a long period, it would be expected that the mercury removal from the liquid fraction would continue to decease and ultimately all of the activated carbon in the column would be gone. DRNA has stated that this problem is an isolated problem and that other units have not shown this problem. The lower bleach concentration appeared to help slow the breakdown over the short duration of this test. If DRNA has solved this problem by using the lower bleach concentration, then removal of mercury can be expected to be even better than shown in the verification test. However, until the issues are resolved, those using the MRU need to occasionally monitor the effluent to determine if it has turned black or contains fine particles, an indication the carbon may be exiting the unit.

4.11.2 Quantitative Factors

There are two basic O&M quantitative factors that apply to the DRNA MRU - electrical usage and chemical usage. The electrical power used was 120VAC, 4 amp for the pump in the unit. The pumps run about 2-3 hours per day, depending on the daily volume in the separator. Total electrical use can be expected to average 2400 watts per day.

The only consumable was the bleach (household bleach was used for the verification test, either commercial or household bleach can be used according to DRNA) used to make the bleach solution. Approximately ten liters of bleach solution were used over the eight-week verification test period. The mixing ratio for the bleach solution was 1 part bleach to 1 part water for the first part of the verification test period and 1 part bleach to two parts water for the last three weeks of the verification test period. Approximately 3.3 liters of bleach was used per two-month period or

1.6 liters per month. DRNA has subsequently changed the recommended bleach ratio to one part bleach to three parts water, which will lower the bleach consumption.

There were no cleanouts or maintenance required during the verification and it would appear that no costs for cleanout would be expected. Based on observation during the recovery of the residuals, the separator has sufficient capacity to hold six months to one year of solids. DRNA provided proprietary information on the mercury adsorbing capacity of the adsorbent material. Based on the weight of adsorbent measured in the MRU, and results of quality control samples that measured the adsorption of mercury on the material, there should be sufficient capacity to treat soluble mercury for six months to one year, assuming the material remains in the unit. The only costs associated with cleanout of the MRU should be the costs to ship the unit to DRNA and costs associated with the recycling service.

4.12 Quality Control Results

The VTP had a detailed QA/QC plan for this test. The VTP contained the QA/QC specifications and overall requirements for this work. Laboratory QA/QC is included with the analytical results in Appendix G. In addition to the normal QC that is run as part of the mercury test procedures, some additional work was also performed on the solids matrix.

Special QC checks using two types of known solids were analyzed for mercury to confirm the recovery in the digestion procedure. . A solid sample matrix with known mercury content was obtained commercially and analyzed during the testing. Recovery was better than 90 percent. There was also concern that the amalgam material might not digest well in the procedure, so a sample of the amalgam from the test site office was obtained. The sample was analyzed and compared to the manufacturer's stated mercury content. Recovery was over 85 percent. Thus, the mercury digestion and analysis procedures were documented as being able to recover these types of mercury materials in the solid matrix.

All of the chain of custody procedures for collecting and transporting samples were followed. Copies of the chain of custody sheets and the various logs documenting the testing are presented in Appendix H.

There were three numerical Data Quality Indicators (DQI) specified for this test program. The precision specification for mercury was a RPD of <20 percent for water matrices and <35 percent for solids. All sample sets analyzed met the precision requirements and every set of mercury analyses had the appropriate number of replicate samples to meet the target of one duplicate per ten analyses. Accuracy, as measured by spiked samples, was specified to meet a range of 80-120 percent recovery for water matrices and 75-125 percent for solids. All water matrices results for spiked samples were within the acceptable range. All but two matrix spikes on the solid samples were within the target range. On two occasions, the recovery was just above the upper target limit (126 percent and 129 percent). These data were reviewed by the NSF QA officer. While the recovery was slightly high, the lab control sample (third party independent standard) was well within range. The recoveries were outside the VTP target, but these values are within the EPA method limits. Based on a review the entire analytical run, including the lab control spikes and standards, the data were considered acceptable. Lab control samples were

analyzed with each analytical batch and all lab control samples were within the ± 10 percent range of true value as established for the mercury method. The QA review of the mercury data showed that the data set did meet the DQI's for precision and accuracy.

In addition to precision and accuracy numerical targets, the VTP had a target DQI for completeness of 90 percent. The data sets were reviewed and all mercury analyses were complete and met the calibration, blank, spike, spike duplicate, standard curve frequencies stated in the QAPP. The only data that fell outside of recovery windows were the two recoveries mentioned above. Two samples delivered to the lab were not analyzed for settleable solids as requested. Based on 44 samples from the characterization test (three types of mercury analysis on each sample) and 32 samples from the verification test (three types of mercury analysis on each sample) the total number of samples for mercury (not including duplicates, triplicates, spikes, etc.) was 228 samples. The four errors or deviations found (2 high recoveries, 2 solid analyses not performed) in a set of 228 samples gives a completeness of over 98 percent. Completeness was also measured for the amalgams surfaces removed or placed, and the total number of samples collected for each part of the test. The VTP stipulated a minimum of 5 weeks (25 samples) of testing with 40 amalgam surfaces per week or 200 surfaces over 25 operating days. Both the characterization period and the verification period exceeded 25 operating days (42 and 29 respectively) and exceed the minimum amalgam removal/placement of 200 (334 and 243 respectively). Therefore, completeness was 100 percent. Forty-four (44) samples were collected during the characterization period and thirty two samples during the verification period, which exceeds the minimum sample requirement. Therefore, the completeness is shown to be 100 percent for sample collection minimum and amalgam surfaces.

All of the QA/QC data and supporting information in presented in the Appendices, including the lab results, field logs, and other supporting documentation.

Chapter 5 – References

(1) NSF International, *Verification Test Plan for the Dental Recycling North America Mercury Removal System*, May 2001

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Additional Reading and Reference Material Supporting the ETV Program

(7) United States Environmental Protection Agency: *Environmental Technology Verification Program - Quality and Management Plan for the Pilot Period (1995 – 2000)*, USEPA/600/R-98/064, 1998. Office of Research and Development, Cincinnati, Ohio.

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(9) United States Environmental Protection Agency: *USEPA Guidance for Quality Assurance Project Plans*, USEPA QA/G-5, USEPA/600/R-98-018, 1998. Office of Research and Development, Washington, DC

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(11) ANSI/ASQC: *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs (E4)*, 1994.

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(13) United States Environmental Protection Agency: *Mercury Study Report to Congress*, December 1997, website www.epa.gov/airprogm/oar/mercury.html

(14) United States Environmental Protection Agency: *Mercury Emissions and Electric Utilities*, February 24, 1998, website www.epa.gov/ttncaaa1/t3/fact_sheets/hg17th.pdf

Appendix A - Operations and Maintenance Manual

Appendix B - Verification Test Plan

Appendix C - Field and Lab Special SOP’s

Appendix D - Spreadsheets with calculation and data summary

Appendix E - Amalgam Surfaces Dental Office Logs

Appendix F – Material Safety Data Sheets

Appendix G - Lab Data Reports and QA/QC

Appendix H - Chain of Custody Records and Field Log Sheets