PHASE II
END-OF-PIPE SUBCOMMITTEE
TECHNOLOGY IDENTIFICATION SUBGROUP REPORT

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This Report is not intended to be an endorsement of any outside company or vendor of a pretreatment technology by the Work Group, the Subcommittee, the Subgroup, or any of its participating persons and institutions, including MASCO and the MWRA, nor is this Report a comprehensive review of existing vendors of pretreatment technologies that could be applied to mercury-containing wastewater streams.

It must be emphasized that the bench-scale tests described in this Report were intended to determine only technical feasibility and were performed on samples of a particular wastestream. Results of similar testing on other wastestream samples may differ. Furthermore, because of the limited nature of bench-scale feasibility testing, any descriptive information and cost estimates provided by vendors relative to full-scale pretreatment systems should be considered as preliminary only.

The bench-scale feasibility test reports, found in Appendix F, were written by the respective vendors. The information in these reports has not been verified by the MWRA/MASCO Mercury Work Group.

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EXECUTIVE SUMMARY

This Report is a product of the Technology Identification Subgroup of the Phase II MWRA/MASCO Mercury Work Group, End-of-Pipe Subcommittee. It presents the results of bench-scale feasibility tests of six mercury pretreatment technologies on samples of a clinical laboratory wastewater. This Report can be used as a resource by facilities that are investigating mercury removal technologies.

The Technology Identification Subgroup was established to determine if there are technologies available that could remove mercury from wastewater to very low microgram per liter (µg/L) or part per billion (ppb) concentrations. In 1995, the conclusions of the Mercury Work Group in Phase I were that no technologies were available to remove mercury to such low concentrations and that no cost-effective removal technologies were foreseen. For purposes of this new study, the Subgroup decided that bench-scale feasibility tests of several promising mercury removal technologies should be performed to address the need for up-to-date information. For each technology, test effluent mercury concentrations would be measured against a goal of 1.0 µg/L (ppb). In addition, the Subgroup decided to investigate the probable costs and spatial requirements of currently available mercury removal systems.

To better understand the characteristics of various medical wastestreams that often contain mercury, another subgroup (the Wastewater Characterization Subgroup) performed a hospital wastewater characterization study. This study was used by the Technology Identification Subgroup to determine what type of wastestream would be most appropriate for the feasibility testing project. The data from the characterization study was also used by the participating vendors identified below to determine what treatment steps, if any, might be needed prior to their mercury removal technologies.

The Technology Identification Subgroup decided to focus its Bench-Scale Feasibility Testing Project on a local hospital's clinical laboratory wastewater stream because such wastestreams have posed difficult compliance issues for hospitals. The selected hospital offered an accessible and consistent, but complex, wastewater stream containing organic solvents, phosphates, suspended solids, various heavy metals, and mercury at concentrations ranging from 11 to 90 µg/L (ppb).

The Technology Identification Subgroup initially performed a literature and Internet search and identified twelve vendors of potentially applicable metals removal technologies. Of these twelve vendors, six vendors elected to participate in the Bench-scale Feasibility Testing Project. The participating vendors were:

- Aero-Terra-Aqua (ATA) Technologies Corporation
- Barnebey & Sutcliffe Corporation
- ICET, Inc.
- KDF Fluid Treatment, Inc.
- Soils N.V.
- SolmeteX, Inc.

Each participating vendor was asked to determine all necessary pre- and post- treatment steps needed for effective removal of mercury from the clinical laboratory wastewater and to consider overall compliance of the pretreated effluent with MWRA sewer discharge regulations. Each vendor was also asked to identify all potentially interfering metals/compounds, suggest an appropriate scheme of unit operations, provide schematic diagrams, address full-scale system considerations, and attempt to estimate preliminary capital and operating costs for 2,000, 20,000, and 50,000 gallon per day full-scale systems.

All six participating vendors submitted draft reports on their test work. The Subgroup reviewed all six draft reports for accuracy and clarity, and issued a list of comments and questions to each vendor. The Subgroup requested the vendors to consider the questions and comments and to submit a final revised report by a specific deadline. One vendor did not submit a final revised report as requested.

Through its Bench-scale Feasibility Testing Project, the Subgroup has found, for samples of one clinical laboratory wastewater stream, that five different pretreatment technologies showed test mercury removal efficiencies that ranged from approximately 44 percent to greater than 99.5 percent. The Subgroup found, therefore, that there are currently available technologies that show potential to remove mercury to very low µg/L (ppb) concentrations. For certain test runs, some technologies achieved the concentration goal of 1.0 µg/L (ppb) mercury on samples of the clinical laboratory wastewater stream.

Regarding full-scale pretreatment systems, preliminary estimated costs and spatial requirements were provided by the vendors of the tested technologies. The Subgroup found that the estimated costs and spatial requirements for many of the proposed systems were comparable to those of classical metal removal systems.

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I. INTRODUCTION / OBJECTIVES

The Technology Identification Subgroup was formed under Phase II of the MWRA/MASCO Mercury Work Group, End-of-Pipe Subcommittee, primarily to identify the technologies with a reasonable potential to remove mercury from a wastestream and to produce effluent concentrations below that being achieved using only source reduction techniques. The Subgroup was assigned to work with vendors of promising pretreatment technologies to help determine the feasibility of each technology to produce low effluent mercury concentrations. The Subgroup would also ask the vendors to provide estimates of full scale system spatial requirements and capital and operating costs. To achieve these goals, the Subgroup decided to ask identified vendors to participate in a Bench-scale Feasibility Testing Project in which the mercury removal technologies were applied to samples of clinical laboratory wastewater.

This report summarizes the work and findings of the Technology Identification Subgroup. The discussions include descriptions of types of hospital wastewater, a hospital wastewater characterization study, species of mercury in wastewater, candidate mercury removal processes, and the Subgroup's Bench-scale Feasibility Testing Project. The testing project discussion includes summaries of interviews with pretreatment technology vendors, testing project protocols (including wastewater selection, analytical testing, and quality assurance and quality control measures), and testing project results.

The Technology Identification Subgroup believes that a review of the information contained in this Report is a good first step for a facility to take when investigating mercury pretreatment systems. However, please note that the Subgroup did not perform an exhaustive search for mercury removal technologies, nor does it endorse any of the vendors that participated in the project. It also must be understood that the feasibility tests were performed on samples of a particular wastestream. Because this project focused on the technical feasibility of the removal technologies, vendor cost estimates must be considered as preliminary only. Individual vendors should be contacted directly for more information about their technologies and about further feasibility and treatability testing.

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II. TYPES OF HOSPITAL WASTEWATER

Wastewater produced by hospitals and by hospital-related industries originates from many sources. The Technology Identification Subgroup assigned the various medical industry wastewater streams into the following four categories:

- wastewater from Clinical Laboratories.
- wastewater from Research Laboratories.
- wastewater from Medical Waste Incinerators equipped with fume scrubbers.
- wastewater from Hospital Laundries.

To understand the characteristics of these wastestreams and the difficulties that might be encountered when attempting their pretreatment, it is important to understand the operations or sources of waste that contribute pollutants to the individual wastestreams. In this way, the chemical constituency of each wastestream can be predicted and potential interferences in a mercury removal process can be anticipated.

The following are brief overviews of typical wastewater-producing processes in each category of hospital facility. Each overview includes an interpretation of the analytical data generated from a wastewater sampling and analyses project that was performed at a representative facility. The wastewater sampling and analysis project was performed by a subgroup of the Phase II Work Group known as the Wastewater Characterization (WWC) Subgroup. Refer to the next section of this report for a summary of the WWC Subgroup project.

Clinical Laboratories:

Most clinical laboratories perform a wide range of services but not every clinical laboratory is the same. Some clinical laboratories are independent of hospitals. Generally, the larger the hospital, the greater the extent of services offered by the clinical laboratory.

The types of processes performed in a clinical laboratory can include: anatomic pathology (including routine histology and cytology), chemistry, drug monitoring and toxicology, hematology, immunology and serology, microbiology, transfusion medicine, and urinalysis. In addition, there can be cytogenetics, flow cytometry, histocompatibility testing, molecular pathology, mycology, and nuclear medicine.

Wastewater from a "typical" clinical laboratory could contain ionic mercury and organomercuric compounds, other heavy metals, organic chemicals, blood products and body fluids, formaldehyde, buffers, dilute mineral acids/bases, phosphates, oxidizers, oil & grease, and particulate materials. Data from the Work Group’s Wastewater Characterization Study suggests that clinical laboratory wastewater would have higher biochemical demand (BOD) and chemical oxygen demand (COD) than domestic sewage. Because there is usually some standardization of work, the wastewater from a specific clinical laboratory may be somewhat consistent in quality and characteristics over long periods.

Research Laboratories:

Perhaps the most diverse and unpredictable wastestreams are those discharged from research laboratories. Many medical institutions are conducting "cutting edge" studies in infectious disease control, blood chemistry, pathology, animal research and inorganic chemistry. Wastes may be produced in significant quantities for short periods or not at all for extended periods. Research laboratory facilities in hospitals can range from one to two laboratory sinks that produce "tens of gallons" each day to hundreds of sinks and related fixtures generating waste volumes in excess of fifty thousand gallons per day.

Wastes can originate from either automated instrumentation or from manual processes and may contain the following pollutants: oxidizers (disinfecting media such as bleach, iodine, peroxides, etc.), radionuclides, proteins (tissue and immunodiagnostics), oil & grease (from vacuum pumps and other rotating equipment), heavy metals (analytical reagents), organic solvents, blood products and other body fluids (urea is a well-known chelator of heavy metals), formaldehyde, phosphates and detergents (from glass cleaning and instrument sterilizing processes), and photographic imaging chemicals (desilvered spent fixer and developer solutions). Data from the

Work Group's Wastewater Characterization Study suggests that (BOD) and (COD) are lower than for clinical laboratories but above average compared with domestic sewage.

Medical Waste Incinerators:

Federal and State regulations closely govern the management of infectious medical or "Red Bag" wastes. Some facilities, trying to reduce the cost of offsite waste disposal, have chosen to install on-site medical waste incinerators to burn these wastes. Air quality regulations typically require the installation of emission controls on the incinerator stacks for particulate and oxides of nitrogen (NO_x) and sulfur (SO_x). Most control systems involve a fume scrubber where pollutants are scrubbed from the waste gas stream into a recirculating water stream. To limit the concentration of pollutants in the recirculating water, part of the water is typically discharged into a sewer system and is replaced with fresh water.

Mercury in the waste gas stream can originate from the waste being burned and also from the fuel used to burn the waste. Red Bag wastes may contain tissue, paper, saturated sorbents, plastics, mercury thermometers, and metallic objects. In some facilities, various animal or human tissues may be disposed of as Red Bag wastes. The liquid wastestream from the incinerator scrubber usually has relatively low concentrations of organic material, oxidizers, but can contain significant concentrations of particulate matter and heavy metals (including mercury). BOD and COD concentrations for incinerator wastewater are usually lower than those of domestic sewage.

Hospital Laundries:

Hospital laundries typically process linens, gowns and lab coats that will contribute a certain amount of organic material, fats, oils and grease (FOG) and an alternating range of pH (alkaline detergent followed by an acidic sanitizer) to the wastestream. This is notably different from a commercial laundry that will commonly process garments, uniforms, wipers, mops and mats often contaminated with heavy metals and petroleum products. Depending upon the processes employed, the hospital laundry wastestream can have elevated temperatures and pH extremes and can contain starch, particulate (including lint), proteins (blood products), detergents, and oxidizers (bleach or other disinfectant). BOD and COD concentrations from laundry wastewater are usually in the normal range for domestic sewage.

Some laundry chemicals (sodium hydroxide and bleach) are known to often have significant levels of mercury contamination. In addition, just one broken mercury thermometer can cause temporary high levels of mercury in the laundry wastewater. Hospital laundry wastewater flows can vary from a few hundred gallons per day to many thousands of gallons per day.

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III. HOSPITAL WASTEWATER CHARACTERIZATION STUDY

A lesson learned in Phase I of the MWRA/MASCO Mercury Work Group was the importance of facilities knowing the characteristics of their wastestreams. A wastewater characterization study can help to identify what and where the sources of mercury are in a facility. The information obtained from the study can be used to rank the order in which the sources should be examined for reduction efforts. The decision to source reduce, segregate, install pretreatment or implement a combination of these options to reduce mercury may be easier when wastewater characterization data is available. The Mercury Work Group views a wastewater characterization study as an essential component of a successful mercury reduction program. Therefore, it was decided that before a Bench-scale Feasibility Testing Project could begin, a wastewater characterization study had to be performed on the various medical industry wastestreams.

Such a study was done by a subgroup of the Phase II Work Group known as the Wastewater Characterization (WWC) Subgroup. As explained in Section VI of this document, the Bench-scale Feasibility Testing Project focused on clinical laboratory wastewater. Therefore, only clinical wastewater data from the study is included in this report. The WWC Subgroup report and analytical test results for the clinical laboratory wastestream are presented in **Appendix B**. Data for the other wastestreams (medical research laboratory, medical waste incinerator, hospital laundry and steam/power generation) can be obtained from the MWRA on request.

Refer to the following Table 1 for an overall summary of results from the WWC Study.

Table 1 (Excel 4.0)

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IV. SPECIES OF MERCURY IN WASTEWATER

The Technology Identification Subgroup has learned that it is important to understand the various species (forms) of mercury that can exist in a wastewater stream and how they can react with other stream contaminants because some mercury pretreatment technologies can effectively remove only certain mercury species. The various chemical species of mercury that can exist in wastewater are: metallic, ionic, and organic. In addition, these various species of mercury may bind to particulate matter in the wastewater to form physical agglomerates containing mercury.

Metallic mercury is typically found in thermometers, manometers, sphygmometers, fluorescent lamps and switching devices. This form of mercury is a silver-colored liquid at room temperature with a specific gravity of 13 (*i.e.*, it is 13 times heavier than water), and it is only slightly soluble in water. Metallic mercury slowly vaporizes at room temperature and can cause dangerous vapor concentrations in enclosed rooms. The vapor form of metallic mercury is readily absorbed through the lungs and is very toxic. Metallic mercury may be combined with other metals to form amalgams (alloys).

Ionic mercury exists when mercury atoms form covalent bonds with halogens and other inorganic ligands (complex ions). Ionic mercury can exist in two forms. With a single atom and an overall +2 charge (Hg^{++}), the ionic mercury is in the mercuric form. The mercurous form is diatomic with an overall +2 charge (Hg_2^{++}). The mercuric form readily forms salts (e.g., mercuric chloride - $HgCl_2$) that are soluble in water. Mercuric chloride and Calomel (mercurous chloride - Hg_2Cl_2) are often used in medical applications.

Organic mercury (typified by methyl mercury) consists of mercury atoms covalently bonded to organic groups. Often called organomercuric compounds, these forms of mercury are quite soluble in water and wastewater and are extremely toxic to aquatic life. These compounds are readily absorbed by fish from their aqueous environment and tend to become highly concentrated (bioaccumulated) in the fish tissues. If fish having bioaccumulated organic mercury are consumed, there can be major human health concerns. In addition, inorganic mercury in the environment can be converted by microbiological activity into methyl mercury compounds that can be absorbed by fish.

The various species of mercury can bind to the particulate matter that may exist in ambient water or wastewater. Particulate-bound mercury can move through the food chain through ingestion (filter feeding organisms) or through re-conversion to dissolved forms. Mercury-laden particulate matter can range in size from tens of microns to sub-micron (colloidal). Typical EPA methodology (Methods 200.7, 200.9, and 245.1) separate dissolved from particulate mercury by filtration through a 0.45 micron (µm) membrane filter.

As a physical species of mercury (instead of the previous chemical species), particulate mercury can often be a significant fraction of total mercury in a wastewater stream. Moreover, accumulations of metallic mercury or mercury-laden solids in plumbing systems (at elbows, traps, and other points) can cause chronic mercury contamination of the wastewater stream.

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V. CANDIDATE MERCURY REMOVAL PROCESSES

The following summarizes the unit operations identified by the Subgroup that could be used in mercury removal pretreatment systems:

Simple Filtration: is designed to remove particulate matter from wastestreams. Filtration is often applied to wastestreams where particulate matter could disturb subsequent unit operations. Since mercury tends to bind to particulate matter, simple filtration (through a 1 to 25 micron or larger rated media) can often be used as a roughing or coarse removal step. Sometimes, the simple filtration step itself may be sufficient. Filtration equipment in this category would include bag type, depth or fiber wound cartridges, and sand or diatomaceous earth media. Nearly all systems would operate under a nominal pressure (typically less than 20 psig), requiring pumped flow as opposed to gravity flow.

Membrane Micro (and Nano) Filtration: is designed for the removal of smaller particulate matter from a wastestream, typically down to 0.1 microns in size. These systems commonly employ synthetic membranes that have pore sizes in the particulate range but approaching the threshold (typically taken as 0.45 microns) that could be defined as dissolved. These systems operate at moderate pressures (60 psig) and offer a variety of cleaning processes (using chemicals or hydraulic back pulses) to restore a fouled membrane. Some membranes are fairly rugged and reusable after cleaning.

Reverse Osmosis: is designed for sub-micron particulate removal and high molecular weight compound removal. Most familiar to hospitals are the reverse osmosis (RO) systems used for the desalinization of incoming city water (often used with ion exchange processes). Most RO membranes are easily fouled by oil and grease and certain organic materials and can, therefore, be destroyed by continuous exposure to chlorine or other oxidants and organic solvents. Operating pressures are elevated (say 200 psig) and membrane performance is expected to degrade typically over a period of two to five years.

Ion Exchange: removes dissolved ionic (charged) molecules from water. Depending upon the ion exchange resin and/or combinations of resins used, it may be possible to achieve nearly total deionization of a wastewater stream and, thereby, produce a pure "megohm" quality product. Ion exchange resins are expensive and are highly susceptible to degradation by oxidizers or fouling by oil and grease and certain organic materials. Most resins are organically derived synthetics that can be adversely affected by biological activity.

Chemical Precipitation/Redox Reactions: are used to convert a pollutant from one form (typically dissolved or soluble) to another form (typically particulate or insoluble). Then, a particulate separation process (usually sedimentation or filtration) is used to remove the resulting particles from the wastestream. The type of chemistry selected for these reactions is dependent upon many conditions (pH, flow, residence time, interferences or synergistic effects of the mixed waste) and success in pollutant removal varies with final pollutant solubility.

Adsorption: is a process involving a combination of concurrent reactions including electrochemical bonding, micro- and macro-reticular pore entrainment and, to a lesser extent, ion exchange (depending upon the presence and form of surface-active functional groups). Activated carbon is a surface-active adsorption medium that is often used for removal of dilute organic solvents from a wastestream. Activated carbon has also been used for removing low levels of heavy metals, including mercury, from both gaseous and aqueous streams. A disadvantage to the use of activated carbon for certain hospital wastestreams, however, may be that the carbon surfaces provide growth sites for biological activity.

Disinfection: is a method for limiting biological activity in the wastestream to reduce possible antagonistic effects in subsequent unit operations. Disinfection may be performed by using chemical methods with hypochlorite, permanganate, ozone, or peroxides (*i.e.*, oxidizers) or by using ultraviolet light (UV sterilization). The choice of method could be dependent upon the forms of biological activity present in the wastestream (*e.g.*, UV might be ineffective on cysts and spores) or subsequent unit operations (*e.g.*, chlorine and hypochlorite may attack certain synthetic membranes, as mentioned earlier). Thermal disinfection (which would leave no chemical residuals in the wastestream) is also an option but is usually impractical because of cost considerations.

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VI. BENCH-SCALE FEASIBILITY TESTING PROJECT

The Technology Identification Subgroup used a multi-step process to accomplish feasibility testing of promising mercury removal pretreatment technologies as follows:

- Identify prospective vendors of mercury removal technologies.

- Make initial vendor contact to solicit interest.

- Review technical summaries submitted by interested vendors.

- Select vendors to invite for interviews.

- Conduct vendor interviews.

- Invite vendors to perform bench-scale feasibility tests.

- Develop a feasibility test protocol.

- Develop a QA/QC protocol and independently analyze raw wastewater and treated wastewater samples.

- Have participating vendors perform bench-scale feasibility tests using actual wastewater samples.

- Review feasibility test reports and develop questions.

- Receive revised feasibility test reports.

- Prepare the final Subgroup report.

A literature and computer/Internet search was initially performed to identify vendors of promising mercury removal technologies, *i.e.*, technologies that can treat mercury-bearing wastewater streams. A total of twelve vendors was identified with systems based in four process technology areas:

- Activated / Modified Carbons - ICET, Inc.; Barnebey & Sutcliffe Corporation; Calgon Carbon Corporation; Westvaco Corporation; and B.G. Wickberg Company, Inc.
- Other Specialized Adsorbents - Aero-Terra-Aqua (ATA) Technologies Corporation; Dynaphore, Inc.; SolmeteX, Inc.; and KDF Fluid Treatment, Inc.
- Enhanced Filtration Systems - US Filter/Memtek Division; and Memtec America Corporation.
- Electrolytic Precipitation Systems - Soils N.V. (Zwijndrecht, Belgium).

The Subgroup prepared a mailing list for the above twelve vendors and sent each vendor a letter to solicit their interest in participating in the Bench-scale Feasibility Testing Project. Copies of the vendor mailing list and the letter appear in **Appendix C**. The letter summarized the objectives of the project and requested that interested vendors submit a letter expressing their interest in participating in the Project along with a technical summary of their technology (*e.g.*, description of the principle of operation, the species of mercury removed, analytical data from any laboratory or field tests).

Of the twelve vendors contacted, the following seven vendors elected to be interviewed by the Subgroup: ATA Technologies Corporation, Barnebey & Sutcliffe Corporation, ICET, Inc., KDF Fluid Treatment, Inc., SolmeteX, Inc., U.S. Filter/Memtek Division, and the B.G. Wickberg Company, Inc. Since Soils N.V. is a Belgium-based firm, it was not interviewed. Of the seven vendors interviewed, five elected to participate in the testing project. Soils N.V. also elected to participate in the project making a total of six vendors that would conduct bench-scale feasibility tests of their mercury removal technologies.

Vendor Interviews

Vendor interviews were completed in December 1996 and in January and April 1997. Each vendor was given a schedule of the proposed interview dates, a statement of goals and objectives for the interview, and an agenda for the interview. Refer to **Appendix D** for a copy of the Agenda for Vendor Interviews. The vendors were asked to limit their presentations to 45 minutes. They were also asked to be prepared to answer technical questions during a 15 minute question-and-answer period that would follow their presentation. The following are summaries of the interviews:

Aero-Terra-Aqua (ATA) Technologies Corporation

ATA's technology is a chemically enhanced sorbent marketed as AQUA-FIX ™. The adsorbent is designed to remove dissolved and ionic forms of metals. The removal process consists of three separate sorption steps:

1. adsorption of the metal ion onto the adsorbent's high surface area,
2. ionic interaction by absorption to polar sites, and
3. chemical bonding of the ions through chelation and ion exchange.

The combination of these processes allows for rapid and substantial metal removal. The adsorbent has been effective in the presence of surfactants and strong chelating agents. The AQUA-FIX ™ beads can be regenerated by rinsing with a dilute mineral acid. The use of filtering devices (such as particulate filters and activated carbon columns) to remove solids and organic compounds before the adsorbent bed has significantly extended the bed life between backwashings and regenerations.

From ATA's experience in applications of their adsorbent technology, the following was found to optimize performance:

1. Increasing retention times (contact) improves metal removal kinetics,
2. Reduction of competing ions and enhancement of metal uptake can be achieved by a two-stage serially-operated AQUA-FIX ™ system,
3. Reduction of organic mercury concentrations with carbon pretreatment can enhance mercury reduction,
4. Frequent column backwashing may be necessary for high solids-bearing wastewater streams, if prefiltration is not done.
5. The optimum pH range for the adsorbent is 5.0 - 8.0 S.U.

Barnebey & Sutcliffe Corporation

Barnebey & Sutcliffe Corporation (B & SC) stated that it is one of only four activated carbon manufacturers in the U.S. and that it makes 80 percent of its products from coconut shells and 20 percent from coal. While not as hard as coconut shell-based carbon, coal-based carbon offers a greater number of macro-pores for adsorption of higher molecular weight compounds such as pesticides. The coal-based carbon also serves as a good substrate for sulfur impregnation at high temperature with a sulfur loading of about 18 percent by weight for optimum performance. In contrast to other sulfur-impregnation methods, the B & SC process does not use any solvent. The B & SC sulfur-impregnated product is called "CB-II."

Several points discussed during B&SC's presentation included the potential for bacteriological fouling of activated carbon and a method to maximize bed loading of mercury. Bacterial growth can occur during periods of no wastewater flow through the bed of activated carbon. The means to prevent biofouling is simply to continue to recirculate wastewater through the system during any extended system "off" period.

To achieve maximum use of the media, two carbon columns are often piped in series. This configuration offers a "roughing" column followed by a "polishing" column. The first column is used until its entire bed reaches full saturation with contaminant, when the column is removed and replaced. The second column removes contaminants escaping the first column (called contaminant breakthrough).

Chlorine and organics can compete with mercury for attachment to adsorption sites in the carbon. B & SC recommended that a full-scale system for mercury removal include an additional column containing standard activated carbon. This third column would be located before the two CB-II columns and would increase the use of the CB-II medium for mercury removal.

To achieve low effluent mercury concentrations, hydraulic loading of a bed of CB-II is typically 3 to 5 gpm per square foot, with a superficial residence time of 12 to 15 minutes. Periodic backwashing of the bed is recommended which may create particulate mercury concerns for the backwash wastewater. Therefore, the backwash would need to be directed back to the main treatment system holding tank for further treatment. Interestingly, it was stated that the sulfur-impregnated carbon performs best at more alkaline pH levels.

ICET, Inc.

ICET is a young research company. ICET has been developing sorbent technologies and is ready to market its first products. The company's expertise is in surface modification of activated carbon and sand to achieve sorbents capable of removing a wide range of heavy metals from wastewater. One company product suggested as a pretreatment step for heavy metals removal prior to mercury removal is a hydroxyapatite-coated sand.

Features of ICET hydroxyapatite-coated sand include:

a. increased surface area, coatings absorb up to 40-60% of its weight in metals,
b. high selectivity and efficiency, dependent on the form used,
c. no requirement for set up or conditioning of the sand bed,
d. easy removal of the metal from the spent medium, and
e. the hydroxyapatite coating is renewable *in situ* allowing the reuse of the sand medium.

Features of ICET activated carbon-based sorbents include:

a. high mercury adsorption capacity,
b. flexibility with respect to mercury levels and flow rates,
c. operation at alkaline or neutral pH,
d. ambient temperature operation, and
e. the ability to recover and recycle mercury.

The potential for wastewater matrix interferences because of the variety of organics, trace metals and viable bacterial organisms present in hospital wastestreams was discussed. ICET recognized that to design a successful pretreatment system for hospital wastewater streams, these factors would need to be considered.

ICET proposed to set up an ambitious bench-scale test system that would continuously pump wastewater through a test system at controlled flow rates. Two flow rates would be examined 1,000 cc/min (120 bed volumes per hour) and 500 cc/min (60 bed volumes per hour). The test system would consist of a prefilter (to remove organic and inorganic particulate), a bed of activated carbon (for organics and additional particulate removal), an ICET media bed (selected for heavy metal removal), and finally an ICET media bed (selected for final mercury adsorption). The wastestream would be sampled after each step of filtration/adsorption and the final product would be collected in 100 ml to 200 ml aliquots at predetermined intervals for analytical testing. The question of funding this test program was not resolved at the time of the interview.

KDF Fluid Treatment, Inc.

KDF's product, a proprietary alloy of copper and zinc called KDF55, creates a galvanic cell when exposed to water. The galvanic reaction is a standard copper-zinc cell and operates because the two chemically dissimilar metals are in direct electrical contact with water. Through this galvanic cell, removal of mercury ions occurs as a metal replacement process, with a copper-mercury amalgam being created on the KDF55 surface. Zinc ions are replaced by the mercury and are released into the effluent stream during the formation of the copper-mercury amalgam. Effluent zinc levels would have to be considered for most facilities in the MWRA service area, since the MWRA has a zinc discharge limit of 1.0 mg/L.

As presented, KDF's media seems to work well with ionic forms of mercury. In a study done by the New Jersey Department of Environmental Protection (NJDEP) on contaminated groundwater, the effluent standard was 2 µg/L. Speciation tests of the contaminated groundwater showed that the mercury was 92 percent inorganic, probably in the chloride form, and 8 percent organic (*e.g.*, methyl mercury) with a total mercury concentration of 10 to 30 µg/L. During the study, treatment by the KDF media produced an effluent of 0.5 µg/L mercury. KDF media was then selected by the NJDEP for full-scale systems. After five years, 200 systems are in operation at about 300 gallons per day each without any removal or replacement of the original beds of media.

SolmeteX, Inc.

SolmeteX has developed a medium over the last two years called Keyle:X™ that is highly selective for ionic forms of mercury. The medium applies the technology of selective chromatography (borrowed from the biotech industry). Since the medium offers much higher selectivity and concentration (loading) factors than other adsorbents, such as ion exchange resins, mercury recovery from the spent medium is possible. Typical saturation loading of Keyle:X™ media is claimed to be 38 to 45 percent mercury by weight. Because of the higher selectivity of the media, the physical size of the Solmetex system is smaller than for other adsorbents. The smaller sizes of the Solmetex systems provide the opportunity for "point-of-use" systems. "Point-of-use" systems can be part of a larger strategy to prevent mercury contamination from reaching large volumes of wastewater.

Saturated Keyle:X™ medium can be distinguished by its change in color from yellow to black as the saturation front moves down the column. SolmeteX manufactures its cartridges in clear PVC so that the color change can be easily observed. A user would send cartridges of fully saturated medium to a reclaimer where they would be burned for recovery of the mercury.

SolmeteX recently found that proper mercury speciation was critical to the success of Keyle:X™ in removing mercury from medical incinerator scrubber blowdown. As a pretreatment step, SolmeteX now does oxidation with hypochlorite solution at a pH of 6.5 to 6.7 to assure that the mercury is converted to soluble ions that can be removed by the medium. Hypochlorite dosing is enough to yield 1-2 milligrams per liter (mg/L) of residual chlorine. Chlorine demand is highly variable depending upon the waste stream. SolmeteX is considering using peroxide or chlorine dioxide (which can be electrolytically generated on-site) as the oxidizing agent. The Keyle:X™ media is not adversely affected by oxidizing agents.

Since other heavy metals are not removed to any great degree, heavy metals removal (if needed) would have to be done as a separate pretreatment step in an upstream column filled with a different medium. Heavy loadings of particulate or oil and grease would require upstream removal.

SolmeteX is currently operating a test system on the wastewater stream from a fume scrubber at a medical waste incinerator. The incinerator and scrubber operate one day per week, during which the flow rate through the SolmeteX system is set at 1.3 gallons per minute. For this system, SolmeteX uses two-stage cartridge prefiltration: 10 microns nominal followed by 1 micron absolute. Then, two cartridges of the Keyle:X™ medium are used in series. The flow through each Keyle:X™ cartridge is one bed volume per minute. Each medium cartridge has a life of about six months, with the second cartridge replacing the first cartridge every three months as a new second cartridge is installed.

With its initial use of hypochlorite at this site, SolmeteX observed a pronounced but temporary increase in the influent mercury concentration. The increase could have been caused by a release of mercury from particulate matter that had adhered to piping surfaces or settled within low points of the system. In five recent runs, two effluent samples had non-detectable mercury (< 0.2 ug/L (ppb)) and all effluent samples had <1.0 ug/L (ppb) of mercury.

<u>U.S. Filter/Memtek Division</u>

Memtek uses a classical metals precipitation approach to wastewater treatment. For mercury removal, Memtek proposed to use sulfide precipitation to convert dissolved mercury to insoluble sulfides followed by chemical coagulation. The theoretical solubility of mercuric sulfide is extremely low: 2.7×10^{-40} mg/L. The metal sulfides would then be removed by membrane cross-flow filtration using a proprietary microfiltration membrane. The resulting slurry would be dewatered by a recessed chamber filter press to form a sludge cake typically containing between 30 percent and 40 percent solids.

In an installation at a battery manufacturing plant, a Memtek system for a wastewater stream containing 20 to 30 µg/L of mercury produces an effluent at about 0.2 µg/L mercury. Memtek has also conducted pilot test studies on scrubber wastewater generated by coal-fired power generating facilities. Mercury was a targeted metal in this wastewater stream. Memtek’s conclusion in these studies was that their chemistry and microfiltration system could reduce mercury and other trace metal contaminants to target levels.

It was proposed that the filtrate water could be polished with an ion exchange resin column to remove any residual mercury not precipitated or removed in the membrane microfiltration system. The physical configuration of the complete system can be designed to fit existing space limitations without compromising system efficiency. Both the ion exchange bed regenerant liquid and the sludge cake would have to be disposed of as regulated wastes.

<u>B.G. Wickberg Company, Inc.</u>

This company markets systems using Mersorb™, a sulfur-impregnated activated carbon. Mercury reacts with the sulfur to form mercuric sulfide that is quite stable and insoluble. The activated carbon material, when saturated with mercuric sulfide, may be disposed as regulated waste (if applicable) or sent to a refinery for mercury recovery. The company claims that the spent carbon will pass the hazardous waste test known as the TCLP test, allowing disposal as a federally unregulated waste. Also, the company stated that sulfur-impregnated activated carbon will not release adsorbed mercury if subjected to temperature or pH changes.

The B.G. Wickberg Company has experience using this product on scrubber system wastewater streams from medical waste incinerators and laboratory wastes. Organic, elemental and ionic forms of mercury are easily removed, but complexed mercury removal has been dependent on the stability of the mercury complex present. In incinerator wastewater streams, mercury has a great tendency to bind to particulate matter. Particulate filtration in combination with the adsorbent was found to reduce mercury concentrations in the incinerator wastewater streams effectively.

Selection of Test Wastewater

The Technology Identification Subgroup realized that there were significant limits on both resources and time for the feasibility testing project. Since the vendors would be asked to conduct all test work without charge, the Technology Identification Subgroup decided that only one type of wastewater would be used in the project.

The Technology Identification Subgroup reviewed the WWC Subgroup sampling program results for the five types of facilities studied by the WWC Subgroup (incinerators, power plants, hospital clinical laboratories and hospital research laboratories). The review suggested that the largest mercury concentrations were from clinical and research laboratories. The clinical laboratory used for this study showed parameter concentrations that were equal to the overall average of the research laboratories parameter concentrations. Both the clinical and the research laboratories showed identical parameters, except that the parameter concentrations for the research laboratories were more variable. The Subgroup decided, therefore, that only the clinical laboratory wastewater would be used for the testing project.

A local hospital agreed to provide samples of their clinical laboratory wastewater for the project. At this facility, clinical laboratory wastewater is currently collected into holding tanks for offsite disposal. Since the wastewater is collected over a period of several days, the holding tanks served to produce composites of the wastewater. Moreover, since the sampling effort for the feasibility testing project involved collection of five gallon samples, the holding tanks also simplified the collection process. Most important, the wastewater had a fairly consistent mercury concentration between 11 and 90 µg/L (ppb).

Analytical and Mercury Speciation Testing

To verify that an adequate mercury level was present and to partially characterize the specific clinical laboratory wastewater, the Technology Identification Subgroup decided to perform analytical testing of raw wastewater samples collected for the Bench-scale Feasibility Testing Project. Representative samples were tested for total mercury and Priority Pollutant Metals.

Total mercury concentration in the wastewater samples was determined by the MWRA Central Laboratory using EPA Method 245.1. This EPA spectrophotometric method is the analytical method of choice because most federal and state regulations address total mercury concentrations in water and wastewater. The method detection limit for the Laboratory was 0.05 µg/L (ppb). The Priority Pollutant Metals analyses were done to help the participating vendors to determine whether any metals were present at levels that could interfere with their mercury removal processes.

As mentioned earlier regarding species of mercury in wastewater, some mercury removal technologies have been fully effective for only specific species of mercury. Therefore, mercury speciation testing of wastewater samples can provide valuable insight into the various mercury species that may be present in a wastewater proposed for pretreatment. To simplify the process of mercury speciation testing for the project, the Subgroup decided to determine only the amount of particulate mercury in representative samples of the clinical laboratory wastewater.

Particulate mercury concentrations were not directly measured, however, but were determined as mathematical differences in analytical test results of total mercury and dissolved mercury. Dissolved mercury concentrations were reported by the MWRA Central Laboratory using EPA Method 245.1 on samples of raw wastewater that had been initially filtered through a 0.45 micron (µm) filter.

The raw clinical laboratory wastewater samples intended for analytical testing were collected at the same time that five gallon test samples were collected for overnight shipment to the participating vendors. All the raw wastewater analytical tests were done by the MWRA Central Laboratory on a two-day turnaround basis so that the resulting data could be sent to participating vendors before the start of their bench-scale tests.

Feasibility Testing and QA/QC Protocols

The clinical laboratory wastewater sample collections began on February 21, 1997. The last sample collection occurred on June 13, 1997. The sample collections were made by experienced MWRA Sampling Associates. Five gallon sample containers were packed in ice-filled coolers for overnight shipment to each participating vendor. Each vendor had an opportunity to specify the desired number of five gallon sample containers for its bench-scale tests. The vendors were asked to handle the samples and conduct the bench-scale feasibility tests according to a detailed written protocol. A copy of this document, entitled "Scope of Work, Feasibility Testing" appears in **Appendix E**.

In an attempt to put all participating vendors on an equal level, the Scope of Work required that several quality control and quality assurance (QA/QC) measures be employed during the testing process from sample collection to the final reporting of data. The Subgroup selected these measures to ensure the integrity, reliability and reproducibility of the test data.

The following is a summary of the QA/QC measures specified in the Scope of Work and some basic reasoning behind the QA/QC goal:

- Sample containers for analytical testing were provided by the Subgroup and were pre-rinsed with nitric acid to ensure that no initial mercury contamination was present. To ensure that mercury contamination was neither initially present nor introduced during test work, the participating vendors were required to complete a mercury analysis of their high purity deionized water (20 samples) and to provide three procedural blanks (*i.e.*, samples of high purity water were carried through the same handling procedure and process as actual test samples). The deionized water samples and procedural blanks were analyzed for mercury contamination by the MWRA Central Laboratory.

- To ensure the integrity of test samples, and to verify claimed mercury and other metals reductions, the vendors were asked to supply split samples of wastewater through each stage of the treatment process to their laboratory and to the Subgroup for analysis by the MWRA Central Laboratory.
- As a final measure of consistency, the vendors were asked to provide a detailed report on their findings in a standard format consisting of:

  - an introduction
  - test materials, procedures, and experimental protocols
  - pretreatment considerations
  - test results
  - full scale considerations (cost estimates, space requirements)
  - discussion / conclusions
  - appendices (including analytical test reports).

As outlined above, the vendor-submitted samples of deionized water and procedural blanks were analyzed for mercury contamination by the MWRA Central Laboratory. The analyses showed that test samples were free of initial mercury contamination and also that mercury contamination was not introduced during the feasibility test work of the vendors. Analytical test results of the submitted deionized water samples and procedural blanks are available from the MWRA upon request.

For vendor-submitted split samples of treated wastewater, mercury analyses by the MWRA Central Laboratory served to verify nearly all corresponding vendor analyses. Refer to **Appendix A** for tables that were developed to summarize and compare MWRA Central Laboratory analytical test data and vendor analytical test data.

For Soils N.V., however, the tables show that there were differences in analytical test results for the submitted samples of both raw and treated wastewater. For example, before Soils N.V. began bench-scale testing, it took five small samples from the five gallon raw wastewater test sample and found an average mercury concentration of 13.6 µg/L (ppb). In contrast, the MWRA Central Laboratory found a higher mercury concentration of 24.9 µg/L (ppb) in a raw wastewater sample collected at the same time as the test sample.

In its feasibility testing report, Soils N.V. claimed to follow the requirements of EPA Method 245.1 during their analytical work. They attributed the difference in mercury analytical results to the difficulty in taking a representative sample from the five gallon test sample container because of heavy particulate in the test sample and to the high fraction of mercury likely held by the particulate.

They were not aware, however, of differences in analytical test results of mercury concentrations for the split samples of treated wastewater that they had submitted to the MWRA Central Laboratory. In contrast to the higher mercury concentration measured in the raw wastewater before it was shipped to Soils N.V. in Belgium, the MWRA Central Laboratory found *lower* mercury concentrations than did the vendor for the split samples of treated wastewater shipped to the United States.

We believe that the specific character of the "before and after" differences suggest that mercury may have been lost from the raw and treated wastewater sample containers by means of evaporation during the lengthy periods of reduced atmospheric pressure for both the East-bound and West-bound trans-Atlantic flights. As a result, because the Soils N.V. analytical tests were done on samples that were not subject to overseas shipment, we have used the feasibility test data and removals performance values of Soils N.V. in this Report. Refer to the summary and comparison tables of **Appendix A** for further details.

Feasibility Testing Project Results

Refer to the following Table 2 for an overall summary of the results from the Bench-scale Feasibility Testing Project. The results suggest, for samples of one clinical laboratory wastewater stream, that five different pretreatment technologies showed test mercury removal efficiencies varying from approximately 44 percent to 99.7 percent, with some final test mercury concentrations at very low µg/L (ppb) levels. Moreover, for certain test runs on the clinical laboratory wastewater, some technologies appeared to achieve the feasibility test goal of 1.0 µg/L (ppb) effluent mercury.

As mentioned above, the Technology Identification Subgroup developed tables to summarize MWRA Central Laboratory analytical test data and vendor analytical test data for the bench-scale feasibility tests of each participating vendor. The summary tables are provided in **Appendix A**. For copies of individual vendor reports on their bench-scale feasibility tests, refer to **Appendix F**.

TABLE 2
SUMMARY OF WASTEWATER MERCURY REMOVALS [1]
BENCH-SCALE FEASIBILITY TESTING PROJECT

Participating Vendor	Number of Test Runs	Influent Mercury (µg/L or ppb)	Final Effluent Mercury (µg/L or ppb)	Test Removals (%)
ATA Technologies Corporation	1	33.0 - 41.3	0.112	99.7
Barnebey & Sutcliffe Corporation	10	21.8 - 24.9	5.16 - 14.2	NA [2]
ICET, Inc.	4	12.8 - 17.1	0.1 - 4.8	71.7 - 99.3
KDF Fluid Treatment, Inc.	2	33.0 - 41.3	18.4 - 20.2	45.6 - 50.5
Soils N.V. [3]	8	10.8 - 17.6	0.8 - 5.0	63.2 - 94.1
SolmeteX, Inc.	9	12.8 - 24.9	0.114 - 1.1	94.4 - 99.2

[1] Unless otherwise noted, these results are based upon mercury concentration data of the MWRA Centeral Laboratory for samples from bench-scale feasibility test runs conducted by the participating vendors on a clinical laboratory wastewater.

[2] For this vendor, percent removals could not be calculated because only static absorption isotherm testing was done by the vendor.

[3] Data is based upon analytical data provided by this vendor. Corresponding MWRA Central Labatory data are 21.8 - 24.9 µg/L (ppb) influent and <0.2 - 2.14 µg/L (ppb) final effluent for test removals of 91.4 - 99.1 percent. Refer to the Report for an explanation.

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VII. OBSERVATIONS

The Technology Identification Subgroup learned much about mercury and its special characteristics in wastewater during this project. Although it was not the intention of the Subgroup to draw conclusions or make recommendations, we would like to share the following observations:

- The Technology Identification Subgroup has learned from this limited feasibility testing project that potentially viable mercury removal technologies may be available in the marketplace. Any technology that showed feasibility (*i.e.*, some level) of mercury removal for the selected clinical laboratory wastewater may be worthy of further study.
- A thorough evaluation of the mercury sources in each wastestream from a facility should be done before a search for pretreatment technologies begins.
- Although it was tailored to specific goals, a wastewater characterization study similar to the one described in **Appendix B** of this report can provide valuable information for both the mercury source evaluation and the pretreatment technology search.
- Each wastewater stream is likely unique and should be subjected to a thorough matching procedure with a specific removal technology if low effluent mercury concentrations are to be achieved on a continuous basis. A critical aspect of the matching process is some type of mercury speciation testing of representative wastestream samples.
- It is important that manufacturers of mercury removal treatment systems understand what species of mercury their technology readily removes. The manufacturers can then determine, in bench-scale feasibility tests, what, if any, initial treatment of the specific wastestream prior to the mercury removal process might be necessary. Since most wastestreams contain several forms of mercury, it is likely that some type of initial treatment will be needed to convert some percentage of the existing various mercury species to one form.
- It is not appropriate to dismiss any specific technology from consideration simply because the technology may appear to remove only one form of mercury.
- Any needed initial treatment steps (such as coarse and fine filtration, oxidation, or carbon adsorption) placed before the mercury removal technology should preferably be determined by bench-scale feasibility and treatability testing for each wastewater stream. Then, further confidence and system design data can be realized by on-site pilot testing.
- One initial goal of the project was to provide an economic analysis of the systems. Because of the variability of feasibility testing procedures employed by the vendors, the Technology Identification Subgroup could not fairly compare the costs of the systems to each other. Also, because of the limited nature of bench-scale feasibility testing, any cost estimates provided by vendors must be considered as preliminary only. However, the Subgroup found that several preliminary vendor cost estimates were competitive/similar to those associated with classical metal removal systems. The Subgroup also found that predicted spatial requirements of many of the full-scale systems were similar to those of classical metal removal systems.

Refer to the individual vendor reports in **Appendix F** for their preliminary full-scale system cost estimates and predicted spatial requirements.

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Appendix A

Bench-Scale Feasibility Testing Project Results - Data Tables

The following tables summarize MWRA Central Laboratory analytical data for raw wastewater samples and for test samples provided by vendors. For each vendor, one table provides mercury concentration data and mercury removal performance (HG-1, HG-2, etc.) based upon analyses performed by the MWRA Central Laboratory.[1] Following the mercury tables are Priority Metals data for each vendor (PPM-1, PPM-2, etc.), accompanied by the raw wastewater data of the MWRA Central Laboratory for the samples used for each test. In addition, there are tables comparing vendor analytical data to MWRA Central Laboratory analytical data (C-1, C-2, etc.). Field names in the tables for vendor data may be inconsistent with the nomenclature used in the vendor reports. The table field names were chosen for consistency to make it easier for the reviewer to understand the steps of the treatment process for each technology. A general explanation of the tables is given below. For information (such as nomenclature) specific to a particular vendor, please refer to the individual vendor reports in **Appendix F**.

MWRA/MASCO Mercury Work Group - Technology Identification Subgroup
Bench-Scale Feasibility Testing Project
Mercury Test Data and Removals
ATA Technologies Corporation

Component	**Raw Wastewater**			**After Prefilter (5 Micron)**		**After GAC Column**		**After 1st Media Column**		**Final Effluent**	**Total Removal**
	Sample 1	Sample 2	Average		Removal		Removal		Removal		
MERCURY	41.3	33	16.5	12.4	66.6%	9.72	21.6%	0.425	95.6%	0.112	99.7%

Analytical data for the raw wastewater collected by MWRA. For this test, the MWRA collected two samples for analysis. The two concentration values are averaged for calculation purposes. The concentration data are reported in µg/L (ppb).

Analytical data for samples collected after each step of the bench-scale treatment process. Removal pertains to how much pollutant is removed at each step and Total Removal is the total percent removed by the entire process. The concentration data are reported in µg/L (ppb).

Appendix A
Index of Data Tables

NOTE: The following tables are all in MS Excel 4.0 workbook format. They are not formatted in HTML, so in order to view them, you must download them to your machine. To do this in either Netscape or Internet Explorer, click your right mouse button on the link to the file you would like to see (on Macs, hold the mouse button down in the link), and a menu will pop up. Select "Save As" (or "Save Target As") and select the appropriate drive and folder on your machine to save to. You may then open the file in Excel. (Some browsers, such as later versions of Internet Explorer, will open the file directly in the browser window by clicking on the link with the left mouse button).

Table Number	Participating Vendor
Mercury Test Data and Removals:	
HG - 1	ATA Technologies Corporation
HG - 2	Barnebey & Sutcliffe Corporation
HG - 3	ICET, Inc.
HG - 4	KDF Fluid Treatment, Inc.
HG - 5	Soils N.V.
HG - 6	SolmeteX, Inc.

Table Number	Participating Vendor
Priority Pollutant Metals Test Data:	
PPM - 1	ATA Technologies Corporation
PPM - 2	Barnebey & Sutcliffe Corporation
PPM - 3	ICET, Inc.
PPM - 4	KDF Fluid Treatment, Inc.
PPM - 5	Soils N.V.
PPM - 6	SolmeteX, Inc.

Table Number	Participating Vendor
Comparison Tables[2] of MWRA Central Laboratory and Vendor Analytical Data :	
C - 1	ATA Technologies Corporation
C - 2	Soils N.V.
C - 3	SolmeteX, Inc.

[1] The table for Soils N.V. also provides mercury concentration data and removal performance based upon analyses performed by Soils N.V. For an explanation, refer to Section VI of this report.
[2] Comparison Tables were not prepared for Barneby & Sutcliffe Corporation, ICET, Inc. or KDF Fluid Treatment, Inc. because these firms did not use outside analytical laboratories in their feasibility testwork.

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Appendix B

Wastewater Characterization Subgroup Report and Characterization Data For A Clinical Laboratory

INTRODUCTION

To help quantify typical concentrations of pollutants in the wastewater from hospital facilities, the Wastewater Characterization (WWC) Subgroup was established under the Phase II MWRA/MASCO Mercury Work Group. The WWC Subgroup obtained wastewater samples from various facilities, submitted the samples for analytical testing, and determined wastewater compositions. The results were intended to help similar facilities understand the composition of their wastewater discharges and to provide pertinent information to the Technology Identification Subgroup.

The WWC Subgroup devised and carried out a rigorous program of sampling of the wastewater from five types of facilities during the Summer of 1996. The types of facilities sampled were: clinical laboratories, medical waste incinerators having wet scrubbers, hospital laundries, steam/power generators, and medical research laboratories.

Three hospitals and one steam producer volunteered to be sampling sites for these five facility types. One hospital agreed to furnish samples of both clinical laboratory and laundry wastewater. Another hospital offered a sampling site for scrubber blowdown from their medical waste incinerator. For the category of medical research laboratories, a large hospital offered six different sampling sites each serving many individual laboratories. For the dual-fueled steam/power generation facility, sampling was done when fuel oil (known to contain mercury) was being burned.

To produce concentration averages, the WWC Subgroup attempted to generate three complete sets of analytical data at each sampling site. Composite samples were collected using automatic compositors at each sampling site over three successive days at all sites, except the power facility, which was sampled for two days. Grab samples were also collected for the parameters requiring grab sampling. All sampling sites were upstream of any existing pH control or other treatment systems.

The sampling work was done by MWRA Sampling Associates, and analytical test work was performed by the MWRA Central Laboratory.

PARAMETERS ANALYZED

The WWC Subgroup chose the following analytical parameters for the characterization effort:

For composite samples:

Alkalinity, Ammonia Nitrogen, Biochemical Oxygen Demand (BOD_5), Boron (Total and Dissolved), Chemical Oxygen Demand (COD), Formaldehyde, Molybdenum (Total and Dissolved), Orthophosphate, Phosphorous (total), Priority Pollutant Metals* (Total and Dissolved), Surfactant (MBAS), Sulfates, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS),

* Antimony, Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Silver, Thallium, and Zinc.

For grab samples:

Cyanide, Chlorine (free), Hexavalent Chromium, Oil and Grease, pH, Petroleum Hydrocarbons, Sulfide, Temperature, and Volatile Organics (via EPA Method 624).

Because the Bench-scale Feasibility Testing Project of the Technology Identification Subgroup focused on clinical laboratory wastewater, the following tables present analytical test results for only the clinical laboratory wastewater samples. The sampling location for the clinical laboratory site is identified as 9001. For ease of review, the tables show results only for parameters that were analytically detected. For reference, however, the names of all tested parameters are listed. The same list of tested parameters applies to all sampling locations of the WWC Study. The WWC Study sampling locations are identified as follows:

Hospital Laundry:	0132	Medical Waste Incinerator:	9000
Steam/energy Producer:	9001	Research Laboratories:	9000, 9001, 9002, 9003, 9004, 9005, 9006.

WWC data for these wastewater streams can be obtained from the MWRA on request.[1]

Wastewater Characterization Data

[1] MWRA, Toxic Reduction & Control Department, Technical Services Section, 100 First Avenue, Charlestown Navy Yard, Boston, MA 02129, (617) 242-6000 x 4900.

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APPENDIX C

LIST OF VENDORS CONTACTED
AND REQUEST FOR VENDOR LETTER OF INTEREST

CONTACTED VENDORS OF METALS REMOVAL TECHNOLOGIES

Aero-Terra-Aqua Technologies Corp.** 1240 Valley Belt Road Cleveland, Ohio 44131 Phone: (216) 459-1930 Fax: (216) 459-1958 James Larson Director of Technology OR New England Sales, Inc. 740 Corporate Park Pembroke, MA 02359 Phone: (781) 826-8855 Fax: (781) 826-2390 Stephen J. Madden	Dynaphore, Inc. 2709 Willard Road Richmond, Virginia 23294 Phone: (804) 672-3464 Fax: (804) 282-1325 Norman B. Rainer, President
Barnebey & Sutcliffe Corporation** 835 N. Cassady Avenue Columbus, Ohio 43219 Phone: (614) 258-9501 Fax: (614) 258-3464 Mohammed Bayati, Technical Director	ICET, Inc.** 916 Pleasant Street, #12 Norwood, MA 02062 Phone: (781) 769-6064 Fax: (781) 762-8204 Shantha Sarangapani President
B.G. Wickberg Company, Inc.*,*** 33 Newport Ave. North Quincy, MA 02171 Phone: (617) 328-9200 Fax: (617) 328-7895 Harry Hadley, President	KDF Fluid Treatment, Inc.** Three Rivers Area Enterprise Park 1500 KDF Drive Three Rivers, Michigan 49093-9287 Phone: (616) 273-3300 Fax: (616) 273- 4400 Jim Jaeckle
Calgon Carbon Corporation P.O. Box 717 Pittsburgh, PA 15230 Phone: (800) 4-CARBON Carl Krause	Memtec America Corporation 5 West Aylesbury Road Timonium, MD 21093 Phone: (410) 252-0800 Fax: (410) 628- 0017 Brett Alexander
SolmeteX, Inc.**, *** 29 Cook Street Billerica, MA 01821 Phone: (978) 262-9890 Fax: (978) 262-9889 Owen Boyd	Soils N.V. ** Haven 1025, Scheldedijk 30 B-2070 Zwijndrecht, Belgium Phone: 32 3 250 55 11 Fax: 32 3 250 52 54 Stany Pensaert
U.S. Filter	Wheelabrator Engineered Systems, Inc.

10 Technology Drive Lowell, MA 01851 Phone: (978) 934-9349, x 2055 Fax: (978) 934-0098 Chris Sakorafos	Memtek Division **** 28 Cook Street Billerica, MA 01821 Phone: (978) 667-2828 Fax: (978) 667-1731 Michael Chan Manager of Process Technology
Westvaco Corporation, Carbon Dept. 205 East Hawthorne Street P.O. Box 140 Covington, VA 24426 Phone: Karen Reynolds	

* Participated in vendor interviews but did not participate in the Bench-scale Feasibility Testing Project.
** Participated in the Bench-scale Feasibility Testing Project.
*** Has a mercury pretreatment system installed on a Boston-area medical waste incinerator.
**** Is now a division of US Filter.

SAMPLE OF SUBGROUP REQUEST FOR VENDOR LETTER OF INTEREST FOR THE BENCH-SCALE TESTING PROJECT

Vendor Name
Address
City/Town, State, Zipcode
Dear Contact Person:
We are writing to you on behalf of the Massachusetts Water Resources Authority (MWRA). The MWRA provides water and sewerage service to the Boston metropolitan area. The MWRA operates a 1 billion gallon per day sewage treatment plant. The EPA, state and MWRA have been focusing increased scrutiny on the impacts of mercury discharges into the environment. The MWRA currently prohibits the discharge of mercury from industrial sewer users within the MWRA service area. Mercury is a bioaccumulating toxic that is prohibited from discharge to ensure that the quality of the treated effluent and biosolids (which are converted into fertilizer pellets) meet applicable state and federal regulatory limits. Facilities in theMWRA service area are obliged to comply with MWRA's mercury enforcement limit of 1.0 part per billion (ppb). Many facilities in the MWRA service area have encountered significant difficulties complying with the MWRA mercury limit and have been subject to MWRA enforcement action.
To help address this problem, the MWRA has established a Mercury Products Workgroup to study mercury sources and to reduce the amount of mercury discharged into the MWRA sewer system. This Mercury Workgroup is a unique public/private partnership formed to resolve the issue of mercury noncompliance. The Workgroup is a collaborative process between the MWRA and the regulated community that stresses cooperation to identify and resolve the problem of mercury in facilities' wastewater streams. A subgroup of the Mercury Products Workgroup is the End-of-Pipe Treatment Technology Identification subgroup. The mission of this subgroup is to identify promising pretreatment technologies through a bench testing program to be conducted by the MWRA. Because the enforceable discharge limit is currently 1.0 ppb, we are looking to evaluate technologies capable of pretreating wastewater streams containing between 1.0 - 1,000 ppb mercury.
There are two primary goals to the bench scale testing program :

- Identify the performance characteristics of selectedpretreatment technologies using samples of actual wastewater streams. Several different types of wastewater will be used in the bench testing program. The Workgroup has expended a significant amount of effort on characterizing various wastewater streams for conventional and nonconventional pollutants. Upon request, a copy of this wastewater characterization study is available for your review.

- Identify interfering matrices in the wastewaters used and the possible solutions to correct for these interferences prior to introducing the mercury containing streams to the pretreatment technology. This step is necessary since some of the wastewater discharges containing mercury are complex, multi-matrix wastewater streams.

We are soliciting your participation in the bench testing program. As a supplier of a mercury pretreatment technology, we are asking for a technical summary of your experience with this pretreatment technology in active applications. This summary should include a description of how the technology works, the concentration levels to which the technology will pretreat and the maximum/minimum concentrations required for the technology to achieve efficient reductions of mercury. The technical summary should also include schematics of the system, the type of mercury removed (ionic, organic, inorganic, complexed, etc.), information on pretreatment required prior to introducing wastewater to the removal technology. We would also like to review analytical data from lab testing and field testing applications of the pretreatment technology. In regard to reporting analytical data, please indicate the minimum detection limit used for all analytical data. The subgroup used a minimum detection limit of 0.2 ppb for all data generated by our wastewater characterization study.

After review of the technical summary, the subgroup would like to invite you to discuss your technology and our planned bench testing program. We also ask for your interest in participating in the bench scale testing.

The results of the subgroup's research findings will be incorporated into a report that will be used to identify promising pretreatment options for facilities operating within the MWRA service area.

We look forward to working with you to identify mercury pretreatment technologies and furthering the goals of the Mercury Workshop initiative. If you are interested in being considered for inclusion in this process, we must receive your written response on or before 8 November 1996.

Should you have any questions, please contact Karen Rondeau, Project Engineer, MWRA, at (617) 241-2347.

Sincerely,

W. Schultz, Co-Chair, Technology Identification Subgroup

A. Pollack, Co-Chair, Technology Identification Subgroup

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APPENDIX D

AGENDA FOR VENDOR INTERVIEWS

Restatement of Goals & Objectives (by Tech ID Subgroup)

- Obtain/clarify submitted information
- Ensure Vendor's understanding of TECH ID Subgroup's purpose in the completion of Bench Scale Testing (BST) and what resources will be required by the Vendor.
- Obtain Vendor's commitment
- Explain time line

Detailed questions to be Answered\Information to be Collected during the Interview:

1. Technical Aspects of the Technology

Flow rate/hydraulic capacities	Types of wastewater treated
Influent/effluent concentrations	Schematics of the system(s)
Known interferences	Mechanism of removal
Case studies	

2. Vendor to make detailed presentation which highlights the elements of his technology (Vendor to identify audio-visual requirements in advance of the interview)
3. Vendor to identify the species of mercury that can be removed (ionic, complexed, particulate, etc.) using his technology.
4. Normal Vendor BST requirements (provide equipment list, schematics, protocols). Recommended type of BST: dynamic system (column tests) with pretreatment options or static "jar" tests. Pilot scale and full scale system scale up considerations.
5. Vendor experience with mercury removal from hospital waste streams (i.e., clinical laboratories, research laboratories, hospital incinerator scrubbers, and hospital laundries). Needed pretreatment steps (flow and concentration equalization, filtration, pH adjustment, organics removal, disinfection, etc.) for optimal performance. For adsorptive media, discussion and supporting breakthrough curves for media capacity and expected loading (milligram Hg per gram of media) at 1 ug/L effluent.
6. What is approximate cost per gallon of your technology based upon existing applications? What is the mercury concentration range of these applications?

Ground rules:

Vendors will be allowed up to 45 minutes to make their presentations followed by a 15 minute Q&A period by members of the Tech ID Subgroup. These members include representatives from the State OTA, MWRA and the Hospital sector that are professionally licensed and holding advanced engineering degrees (MS, PhD). Therefore, Vendors should be prepared to answer fairly technical questions during the Q&A period. Total Vendor presentation will not exceed one hour.

No Vendors will be allowed in the room while another Vendor is making a presentation. This will be done in an effort to help ensure that sensitive or proprietary information is not divulged by a Vendor to a potential competitor.

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APPENDIX E

BENCH-SCALE FEASIBILITY TESTING PROJECT
SCOPE OF WORK
2/10/97

MWRA/MASCO Hospital Mercury Work Group
End-of-Pipe Subcommittee, Technology Identification Subgroup

Objectives

The Technology Identification Subgroup (the Subgroup) has established a project goal of bench-scale testing of promising treatment technologies for Mercury removal from wastewater. The testing is to be performed by Suppliers of the technologies using a sample of hospital clinical laboratory wastewater. The testing is to include "systems" considerations for handling of interfering wastewater constituents and for optimization of the Mercury removal process relative to an effluent concentration goal in the order of 1 microgram per liter (µg/L). In the test report, the Supplier shall include discussion of the Mercury removal process relative to the need for (or advantages of) raw wastewater equalization, pH control, and biological sterilization and for final treated effluent neutralization. The discussion shall consider the allowed effluent pH range to be 5.5 to 10.5 Standard Units. The Supplier shall perform sufficient bench-scale testing to allow preliminary estimation of full-scale (24 hours/day) system capital and operating costs for wastewater flows of 2,000 gallons per day (GPD), 20,000 GPD, and 50,000 GPD. The Supplier shall detail the cost estimates in the overall test report and shall explain any omissions from or limitations in the estimates. The Supplier shall also estimate full-scale system space requirements (L x W x H) for each of the three flows along with a typical equipment layout diagram.

Attachment 2 provides information that you may want to consider prior to performing the feasibility testing.

Shipment of Raw Wastewater Sample from the Subgroup to Supplier

The raw wastewater sample (quantity to be determined) will be collected by the Subgroup from an existing collection tank and will be shipped to the Supplier via overnight express. At the time of collection, an aliquot of the sample will be taken and analyzed for total and dissolved Priority Pollutant Metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc) by the Subgroup. The analytical laboratory report will be faxed to the Supplier as near to the sample delivery time as possible. The sample is expected to have a Mercury concentration between 20 and 40 µg/L. Other chemical parameters shall be assumed to be similar to the results of a comprehensive characterization study that was previously performed by the Subgroup on a sample of the wastewater. The Supplier shall use proper equipment and sample handling procedures for personnel protection and safety when handling clinical laboratory wastewater. For scheduling purposes, the Subgroup will begin collection and shipment of the wastewater sample on or near February 24, 1997.

Quality Control

Verification of Proper Sampling and Analysis Techniques

(Note: The Subgroup acknowledges that the following quality control procedures may be cumbersome to the Supplier. If you have a QC program that is comparable to the one described below, please submit a description of the program for review by the Subgroup.)

Within five days after the Supplier has received the raw wastewater sample and empty sample bottles, the Supplier shall prepare for analysis:

- 10 high purity deionized water samples (500 ml sample volume required) prepared in the Supplier's laboratory using the Supplier's own high purity water supply and its own prepared sample bottles.
- 10 additional samples of the Supplier's high purity deionized water collected in the sample bottles that the Subgroup supplies.

The Supplier shall send 5 of each type of sample to the Subgroup for analysis. The remaining ten samples shall be analyzed by the Supplier's lab. Please fax these results to: Karen Rondeau, MWRA, at (617) 241-2301.

Procedural Blanks

A minimum of three procedural blanks (high purity water carried through the same sample handling procedure and processes as the samples) from each experimental run shall be performed.

Sample Handling and Analysis

- The Supplier shall collect and analyze as many samples during testing as he/she deems necessary for determination and optimization of each element of system performance. **At a minimum, the Supplier shall provide mercury data for each treatment step and final treated effluent for each test run.** Please see Attachment 1, Guidelines for Sample Collection and Processing.
- The Supplier shall indelibly and clearly mark each sample bottle label for identification of contents, test run, treatment step, date, and qualifying comments. These requirements apply to test samples intended for local analysis and, as outlined below, to test samples to be returned to the Subgroup.
- The Supplier shall perform on-site preservation of test samples by addition of concentrated nitric acid to reduce sample pH to less than 2.0 standard units.
- The Supplier shall perform EPA method 245.1 for total Mercury analyses with equipment and personnel capable of achieving a method detection limit of 0.2 µg/L.
- In an overall test report, the Supplier shall include copies of all executed "chain-of-custody" sheets and analytical laboratory test reports. Each laboratory test report shall clearly identify sample contents, test run, treatment step, date, and qualifying comments. In addition, careful documentation and reporting of the result of sample preparation and analyses, including those of individual replicates and blank samples should be provided.

Samples to be sent back to the Subgroup

Along with the raw wastewater sample, the Subgroup will ship empty analytical laboratory sample bottles and "chain-of-custody" sheets. The Supplier shall submit to the Subgroup, the following samples for analysis:

- 5 high purity deionized water samples (500 ml sample volume required) prepared in the Supplier's laboratory using the Supplier's own high purity water supply and its own prepared sample bottles.
- 5 additional samples of the Supplier's high purity deionized water collected in the sample bottles that the Subgroup supplies.
- 1 procedural blank from each test run.

- A **split sample** of final treated effluent from each test run. A split sample is a subsample of the same sample that the Supplier analyzes.

Subgroup sample bottles intended for metals analyses will be so labeled by the Subgroup and will be inoculated with nitric acid prior to shipment. The Supplier shall check pH after filling and shaking the sample bottle and, if needed, shall add concentrated nitric acid to assure that the contained sample pH is less than 2.0 Standard Units for preservation until subsequent laboratory analyses by the Subgroup. The Supplier shall be responsible for ensuring that its testing staff exercises proper and safe handling of the sample bottles and nitric acid.

All filled Subgroup sample bottles shall be stored at $4^{o}C$ maximum by the Supplier until shipment by overnight express (paid for by the Supplier) to the Massachusetts Water Resources Authority Central Laboratory. The deionized water samples shall be shipped back to the Central Laboratory in the cooler originally used for wastewater sample shipment. The Supplier shall refill the cooler with ice before shipment and shall pack the cooler to minimize the likelihood of sample bottle damage during shipment. The shipment shall be clearly labeled with "*Project Code HGTECH*" and shall be made to the following address:

Ms. Polina Eppelman
Massachusetts Water
Resources Authority
Central Laboratory
Deer Island
Boston, MA 02152
Project Code: HGTECH

Feasibility Test Report
The Supplier shall issue the test report approximately four weeks after the conclusion of testing (*i.e.*, around the end of March 1997). If possible, the following test report format shall be used:

I. Introduction/Background
II. Test Materials, Procedures, and Experimental Protocol
III. Pretreatment Considerations
IV. Test Results
V. Full Scale System Considerations (Cost Estimates, Siting, etc.)
VI. Discussion/Conclusions
VII. . Appendices (including analytical test reports)

In the test report, the Supplier shall include descriptions of:

- system process steps,
- preferred Mercury speciation,
- inactivation of complexing agents that could limit Mercury removal,
- test Mercury removals through each process step, and
- full-scale system operation and control considerations.

In the test report, the Supplier shall include discussion of the Mercury removal process relative to the need for (or advantages of) raw wastewater equalization, pH control, and biological sterilization and for final treated effluent neutralization. The discussion shall consider the allowed effluent pH range to be 5.5 to 10.5 Standard Units. The discussion shall also consider the rather large daily and hourly variabilities that, depending upon the clinical laboratory facility, could occur in the wastewater flow, pH, mercury concentration, and the presence and concentration of potentially interfering and mercury-complexing chemicals.

Contact Person for Public Document

Since the Subgroup is associated with the Massachusetts Water Resources Authority, an agency of the Commonwealth of Massachusetts, the test report will become part of a public document. Accordingly, the Supplier is invited to include name(s) of a contact person or persons with mailing addresses and telephone/fax numbers for future inquiries by other parties.

ATTACHMENT 1

Recommended Guidelines for Sample Handling and Processing

Because the mercury content of samples, especially after pretreatment, may be close to or less than that detectable by EPA method 245.1, contamination during the collection and processing of samples may severely compromise the integrity of the analysis and subsequent interpretation of results of any experiments conducted. Contamination and analytical problems in analysis of trace concentrations of mercury are well known and provide significant challenges for most laboratories. The following are recommendations to minimize these potential problems:

- Use extreme care in the collection and processing of samples. Typically the collection of several hundred mls for analysis is required, more if replicate analysis is to be conducted or sample splits prepared. Contamination from dust and residual vapor phase mercury, improper handling (plastic gloves should be used at all times), improperly cleaned labware and cross-contamination from samples with very high mercury concentrations are especially prevalent sources of error.
- Labware in contact with samples should be cleaned by use of a common laboratory detergent and then acid-cleaned either in hot concentrated nitric acid or by soaking in 6M HNO_3 overnight followed by thorough rinsing with high purity deionized water.
- The use of Teflon or glass labware is preferred to minimize sorption losses. Sample containers (glass stoppered 500 ml Erlenmeyer flasks or 500 ml Teflon bottles are useful) should be stored in plastic bags after cleaning and after filling with sample to minimize the possibility of contamination. If possible, do not use sample bottles previously containing samples with high concentrations of mercury to collect samples you anticipate will have mercury at much lower levels (e.g. after treatment). After cleaning and in between use, store sample bottles filled with 10% HNO_3 prepared using high purity deionized water.
- Because many laboratories have difficulty in producing high quality results at 1 ug/l or lower, you may wish to pre-evaluate the capabilities of the laboratory (and your ability to prepare clean sample bottles) by sending the lab you plan to use approximately five samples of your high purity water. If the results are erratic, you will need to evaluate whether the lab or your sampling technique is the source of error. Inability to consistently achieve mercury concentrations less than the detection limit in high purity deionized water samples should be of concern and perhaps require the use of another laboratory.

ATTACHMENT 2

Additional Information Concerning Pretreatment Considerations

The Subgroup has obtained information regarding the field testing of an innovative mercury removal technology that is being conducted through the assistance of the Massachusetts Strategic Envirotechnology Partnership (STEP) program. The testing of this system has been underway for about four months. While this testing was conducted on scrubber wastewater from a medical waste incinerator, rather than clinical laboratory wastewater, it has yielded information which we feel would be useful to the Supplier in the performance of this feasibility testing:

- Mercury speciation studies revealed that the forms in which mercury may be found are both complex and variable. The results showed that a significant amount of the mercury in the wastewater are bound to colloids and particulates in suspension (as much as 64% in one sample), or exists in the form of organic complexes.
- Based on these speciation results, a number of pretreatment techniques were evaluated to either remove the non-binding forms of mercury or to release the bound mercury to allow the removal system to recover it: chlorination, using hypochlorite; ultrafiltration; activated carbon; and reducing the pH of the wastewater. The use of hypochlorite was found to be the best approach, resulting in significant improvement in the performance of the system. The system was consistently able to remove >99.5% of the mercury (at feed levels of 500 to 10,000 ppb) to discharge levels of under 5 ppb when hypochlorite was used. The optimal pretreatment was to add sufficient hypochlorite to reach a level of 1 - 5 mg/L residual chlorine with a 15 - 30 minute reaction time.
- The initial work with hypochlorite used an ORP electrode to measure the residual chlorine level. This approach, however, was found to be somewhat inexact and time consuming, and was replaced with a wet chemical method using the DPD colorimetric test.

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APPENDIX F

VENDOR BENCH-SCALE FEASIBILITY TEST REPORTS

ATA Technologies Corporation
Barnebey & Sutcliffe Corporation
ICET, Inc.
KDF Fluid Treatment, Inc.
Soils N.V.
SolmeteX, Inc.

This section of the report is not available online.
For a copy of this appendix, please contact
David Eppstein at MASCO.
deppstein@masco.harvard.edu
Phone: (617) 632-2860
Fax: (617) 632-2759

REFERENCES

Ambient Water Quality Criteria for Mercury, EPA 44/5-80-058, October 1980.

Reducing Mercury Discharge at a Testing Laboratory, Massachusetts Strategic Envirotechnology Partnership (STEP) and Massachusetts Office of Technology Assessment (OTA).

"Guidelines Establishing Test Procedures for the Analysis of Pollutants," Code of Federal Regulations, Title 40, Part 136 (40 CFR 136).

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