INNOVATIVE TECHNOLOGY
Summary Report

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Mercury Contamination – Amalgamate (contract with NFS and ADA)

Stabilize Elemental Mercury Wastes

Mixed Waste Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
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Mercury Contamination – Amalgamate Mercury (contract with NFS and ADA)

Stabilize Elemental Mercury Wastes

OST Reference #1675

Mixed Waste Focus Area

Demonstrated at
Pacific Northwest National Laboratory
Richland, Washington

INNOVATIVE TECHNOLOGY

Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://OST.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Summary

Through efforts led by the Mixed Waste Focus Area (MWFA) and its Mercury Working Group (HgWG), the inventory of bulk elemental mercury contaminated with radionuclides stored at various U. S. Department of Energy (DOE) sites is thought to be approximately 16 m^3 (Conley et al. 1998). At least 19 different DOE sites have this type of mixed low-level waste in their storage facilities.

The U. S. Environmental Protection Agency (EPA) specifies amalgamation as the treatment method for radioactively contaminated elemental mercury. Although the chemistry of amalgamation is well known, the practical engineering of a sizable amalgamation process has not been tested (Tyson 1993). To eliminate the existing DOE inventory in a reasonable timeframe, scaleable equipment is needed that can:

- produce waste forms that meet the EPA definition of amalgamation,
- produce waste forms that pass the EPA Toxicity Characteristic Leaching Procedure (TCLP) limit of 0.20 mg/L,
- limit mercury vapor concentrations during processing to below the Occupational Safety and Health Administration's (OSHA) 8-hour worker exposure limit (50 $\mu g/m^3$) for mercury, and
- perform the above economically.

Additional major test objectives were to determine the mercury vapor pressure above the product and to assess the treated wastes' resistance to degradation in a broad pH range.

ADA Technologies, Inc. and its subcontractors developed a process to meet the above criteria using commercially available equipment. Initial testing was performed on surrogate waste, followed by demonstrations on two actual mixed waste streams. Treatment of liquid mercury was conducted by adding powdered sulfur to the pug mill. The pug mill used in these tests was a relatively small unit with a dual shaft mixer that accommodated approximately 0.06 m^3 of material (Figures 1 and 2). As the mixing blades turned, mercury was poured into the mill. As the mill continued to mix and reactions took place, additional chemicals were added. The temperature of the mixture was monitored and samples were taken periodically and analyzed for free mercury. Processing was performed at ambient conditions without the addition of heat. Water vapor and heat were evolved during processing. Room air was swept over the pug mill and then filtered to remove mercury vapors from the mixing area.

Figure 1. View of pug mill used by ADA Technologies to stabilize mercury waste.

Figure 2. Top view of ADA Technologies' pug mill showing blades, fan, and lid.

Demonstration Summary

In previous years, several treatability studies and other development efforts have been performed throughout the DOE complex related to amalgamation of mercury wastes. Such studies have used various materials to stabilize mercury. However, until now, no studies beyond bench scale had been conducted. Consequently, the primary technical issue associated with the amalgamation of mixed waste mercury was related to scale-up of the process to a cost-effective operations level. For this reason, the HgWG issued a Request For Proposal (RFP), MER01, to industry in November 1996 entitled, “Demonstration of the Amalgamation Process for Treatment of Radioactively Contaminated Elemental Mercury Wastes” (Simpson 1996).

The MER01 RFP sought to demonstrate the technical feasibility of and acquire engineering data for using amalgamation to treat radioactively contaminated bulk elemental mercury at DOE sites. One vendor selected was ADA Technologies (ADA), located in Englewood, Colorado. Subcontracting with Colorado Minerals Research Institute (CMRI) of Golden, Colorado and Advanced Integrated Management Services, Inc. of Arvada, Colorado, ADA received bulk elemental mercury-mixed wastes and performed a demonstration of their technology, applying their amalgamation process to treat two DOE waste streams.

ADA was selected to participate in the amalgamation demonstration program with their process for stabilizing radioactively contaminated elemental mercury with sulfur. The process combines and mixes waste mercury with sulfur in a commercially available pug mill to produce a stable mercury sulfide product. The process equipment is shown in the photographs in Figures 1 and 2. Although the ADA amalgamation process uses a proprietary sulfur mixture, pug mill mixers are commonly used in metallurgical and chemical operations where intense mixing of pasty material is required. These types of mixers and their relationship to other industrial mixers have been well described elsewhere (Faulkner and Rimmer 1995).

The pug mill was manually decontaminated after processing each waste stream. After processing, the waste was returned to the shipping container and packaged in accordance with U. S. Department of Transportation (DOT) and waste disposal facility requirements.

Other private waste treatment companies have approached ADA and its subcontractors concerning future collaborations using this process. However, at this time, they have no specific plans for the use of this process or equipment.

Key Results

The key results of the demonstration are as follow:

- The process was developed and demonstrated. By use of a proprietary additive mixture, greater than 99.9% extent of reaction was achieved and Technology Development Requirements Document (TDRD) vapor pressure requirements were met. The product achieved TCLP results consistently below 0.1 mg/L.
- The pug mill was shown to be well-suited to the process because of its ability to adequately mix the components and control the residence time to ensure complete reaction. The use of a commercially available mixer was demonstrated.
- Radioactive contamination control requirements were readily implemented using the pug mill.
- The process is readily scalable to easily match the treatment needs at individual DOE sites.
- The product satisfies the EPA’s definition of an amalgam as given in 40 CFR 268.42, Table 1, meeting disposal requirements outlined in the Resource Conservation and Recovery Act (RCRA).

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SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Schematic

The EPA specifies amalgamation (AMLGM) as the best demonstrated available technology for the treatment of radioactively contaminated elemental mercury. EPA has defined AMLGM in 40 CFR 268.42 Table 1 as:

> Amalgamation of liquid, elemental mercury contaminated with radioactive materials utilizing inorganic agents such as copper, zinc, nickel, gold, and sulfur that result in a nonliquid, semi-solid amalgam and thereby reducing potential emissions of elemental mercury vapors to the air.

The DOE has in its legacy inventory approximately 16 m^3 of this type of waste in storage at 19 different sites. Demonstrations were performed with the following objectives in mind [as found in the Technology Development Requirements Document (TDRD) for Mercury Amalgamation (MWFA 1996)]:

- meet the EPA definition of amalgamation,
- pass the TCLP limit for Hg in nonwastewaters of 0.20 mg/L,
- limit mercury vapor concentrations during processing to below the OSHA 8-hour worker exposure limit of 50 $\mu g/m^3$, and
- perform the above economically.

Additional major test objectives were to determine the mercury vapor pressure above the final waste form and to assess the resistance of treated wastes to a broad pH range. Personnel at the Oak Ridge National Laboratory (ORNL) will measure these two sets of parameters and the results will be published separately.

The ADA amalgamation process consists of combining liquid mercury with a proprietary sulfur mixture in a pug mill. Metal sulfides such as HgS have extremely low solubilities across a wide range of pH values (Connor 1990). Pug mill mixers are commonly used in metallurgical and chemical operations where intense mixing of pasty material is required. Tens of thousands of such systems are used industrially today. A few of the manufacturers of pug mills for chemical stabilization of contaminated soils and sludges include Portec Chemical Processing Products (Yankton, South Dakota), Pugmill Systems, Inc. (Columbia, Tennessee), Marion Mixers (Marion, Iowa), and Scott Equipment Company (New Prague, Minnesota). A brief description of these types of mixers and their relationship to other industrial mixers can be found in Kirk-Othmer's encyclopedia (Faulkner and Rimmer 1995).

The pug mill used in these tests was a small unit with a dual-shaft mixer that accommodated approximately 0.06 m^3 of material (Figures 1 and 2). This mill was 0.9 m long and had a 0.1-m^2 cross-section. Its mixing blades were 14 cm long and overlapped for more efficient mixing. A liner was placed in the pug mill to reduce the dead volume beneath the blades. The typical rotation speed of the pug mill blades was 50 rpm. This size of pug mill would accommodate the desired full-scale processing rate of 40 kg of mercury in an 8-hour shift with no difficulty.

Description of Waste

Two waste streams were studied and treated during the course of this demonstration: 112 kg of contaminated waste mercury from the Los Alamos National Laboratory (LANL) and an additional 20 kg of waste mercury from Fernald. The radioactivity level in the mercury from both sites was quite low and, in fact, no radioactivity was detected with a standard gamma scan.

The LANL waste arrived at CMRI in a 55-gal drum containing another small drum holding five flasks of mercury (Figure 3). The waste was contained in metal flasks with metal screw plugs. Fill material around the flasks consisted of vermiculite.

Figure 3. Los Alamos National Laboratory (LANL) waste upon arrival.

The Fernald waste arrived at CMRI in half-pint jars placed within several 5-gal cans. The jars had been double-bagged before being placed inside the cans. The waste contained significant amounts of water; this water was added to the pug mill along with the mercury waste.

System Operation

Treatment of the liquid mercury was conducted by adding powdered sulfur to the pug mill (Figure 4). The mercury was poured from the original flasks into a tared plastic beaker and weighed (Figure 5). Then as the mixing blades were turning, the preweighed amount of mercury was poured into the mill. As the mill continued to mix and the reaction took place, additional chemicals were added. The temperature of the mixture was monitored, and samples were taken periodically and analyzed for free mercury. Mixing was

Figure 4. Sulfur in the pug mill before the addition of mercury.

Figure 5. Sampling mercury before treatment.

concluded when the reaction exotherm subsided and the free elemental mercury analysis indicated that more than 99% of the mercury had reacted. The details of the process were the subject of a patent application.

The processing of mercury in the pug mill was performed without the addition of heat. The reaction of mercury with sulfur is exothermic at room temperature, and the mixture increases in temperature during processing. Water vapor is also evolved. The temperature was monitored during processing, and the air above the pug mill was swept to remove mercury vapors from the mixing area. The sweep air was filtered through a HEPA filter and then passed through a sulfur-impregnated carbon filter to capture the mercury. The formation of mercuric oxide was not a concern due to the relatively low processing temperature.

Processing of the waste was performed in ambient environmental conditions. Mercury vapor concentrations above the pug mill were below the Threshold Limiting Value (TLV) of 50 $\mu g/m^3$. Therefore, operators were able to monitor the mixing and add reagents to the mixture as required without any special precautions, although all operators wore respirators fitted with cartridges designed to remove mercury vapor.

The free-mercury tests were performed using one stage of a sequential extraction method developed by Lockheed Environmental Systems and Technologies Company (LESAT), which is the contractor for the Environmental Monitoring Systems Laboratory–Las Vegas. The stage of the extraction method used in this treatability study separated elemental mercury and metallic mercury amalgams from mercury sulfide based on solubility differences in a hot 70% nitric acid solution.

The pug mill was manually decontaminated after processing each waste stream. Swipe tests confirmed the effectiveness of the decontamination effort. The ADA process itself does not create secondary wastes associated with pretreatment of the liquid mercury (such as removal of oxidized mercury compounds).

The ADA process appears to be robust, meaning that the process easily accommodates contaminants in the waste such as water or other heavy metals. In particular, small amounts of water in the feed streams did not adversely affect the amalgamation process or add to the secondary waste stream volume.

After processing, the waste was returned to the shipping container and packaged in accordance with DOT and waste disposal facility requirements. Containers that were not 90% full (as specified in DOE regulations) were topped off with vermiculite or another material to fill the container.

The product from the ADA mercury amalgamation process was found to meet current Envirocare of Utah Waste Acceptance Criteria (WAC) for disposal. (Envirocare is currently the only licensed/permitted disposal outlet for mixed low-level waste.) However, if these WAC change such that additional processing is required (such as compressive strength), a postprocessing step involving cementation could be added to the treatment train.

Further steps in the treatment train may be required for some wastes. While this demonstration focused on elemental mercury wastes, other waste such as debris may require pretreatment before it can be processed by amalgamation. Early steps in the treatment train could include sorting, shredding, slurrying, or a combination of steps.

SECTION 3

PERFORMANCE

Surrogate Waste Test Results

The reactions of mercury with a variety of amalgamating agents are exothermic and, in principle, should proceed at room temperature. In practice, the mixing of the mercury with the amalgamating agent is the principal difficulty to overcome. Nearly 100% extent of reaction can be achieved when small quantities of mercury are reacted in the laboratory with conventional shakers or manual stirring. However, to meet the process throughput stipulated in the TDRD (MWFA 1996), the desired volume of mercury waste to be treated in each batch is 3 L. Therefore, the goal of the surrogate tests was to demonstrate efficient mixing of 3 L of mercury with the requisite amount of sulfur. Use of a commercially available mixer was an important part of the process development strategy to demonstrate the ability to scale up the process and aid in achieving economic viability.

During initial surrogate tests, only 50% of the mercury reacted with powdered sulfur using the pug mill equipment. When the process was changed to use a proprietary additive mixture, up to 98.8% of the mercury was reacted.

The mercury load was then reduced to 1 L, and the process was repeated using the additive mixture. This resulted in 99.9% extent of conversion of the mercury, but the TCLP results of the treated samples were in the range of 1.2 to 2.6 mg/L, well above the statutory limit of 0.2 mg/L. However, adding sand to the mixture was discovered to provide results of greater than 99.9% extent of reaction and TCLP results were consistently below 0.1 mg/L, even when the mercury load was increased. The addition of sand may have aided in the reaction by mechanically disrupting the mercury droplets, allowing the chemicals to contact more closely. During this phase of testing, several forms of sulfur were tried in combination with varying amounts of sand. The resulting formulation and processing conditions formed the basis for the patent application.

Test Results with Radioactively Contaminated Mercury

Once the surrogate tests were completed, tests were conducted with actual waste materials. The treatment process was the same as described in the surrogate tests.

Treatment of Waste

Using the methods and parameters developed in the surrogate testing phase, five batches of waste mercury were treated. The entire quantity of waste mercury from LANL was treated in four batches. The weights of mercury treated in these batches were 23, 28, 33, and 28 kg, respectively. The treatment conditions for all four of the LANL batches were similar. No attempt was made to perform statistical experiments. The 20-kg batch of mercury from Fernald was treated as a single batch.

At the end of each treatment, the mass concentration of the unreacted mercury was determined. Analyses showed that the extents of reaction (1 minus the free mercury, expressed as a percentage) in these batches were 99.93, 99.92, 99.87, 99.94, and 99.98, respectively. TCLP tests were performed internally and showed less than 0.1 mg/L of leachable mercury. This is below the 0.2-mg/L level required to pass the TCLP. The mercury waste loading was approximately 57% for the process, which is above the TDRD requirement of 50%. This requirement aids in minimizing disposal volumes and associated costs.

While mixing the waste, the vapor-phase mercury concentration above the stabilized waste was monitored using a Jerome mercury analyzer. The analyzer was capable of measuring 10 • g/m^3 of mercury in air. In all cases, the concentration of mercury above the waste was below the OSHA 8-hour worker exposure limit of 50 • g/m^3. TCLP and mercury vapor concentrations are summarized in Table 1. The internal TCLP tests were performed on a representative sample from each batch. The detection limit for the internal laboratory was only 0.1 mg/L, so an exact value was not obtained for each batch.

However, all batches were below the 0.1-mg/L detection limit. This shows consistency between batches for the process.

Table 1. Mixed waste treatment results (internal laboratory).

Waste Origin	Batch Size (kg)	% of Hg Amalgamated	Hg Vapor Concentration ($\mu g/m^3$)	TCLP-Leachable Hg (mg/L)
LANL	23	99.93	<50	<0.1
LANL	28	99.92	<50	<0.1
LANL	33	99.87	<50	<0.1
LANL	28	99.94	<50	<0.1
Fernald	20	99.98	<50	<0.1

Results of Certified Laboratory Tests

Before sending samples to a laboratory for TCLP and other required tests, the four batches of treated waste from LANL were blended. Representative samples of this waste stream and the Fernald waste were submitted to ACZ Laboratories, Inc., a Utah-certified laboratory.

Results of TCLP tests performed at ACZ Laboratories further corroborate the results of the internal analyses. The TCLP results from ACZ were 0.048 mg/L for the blended LANL waste and 0.0349 mg/L for the Fernald waste. Again both were well below the 0.2-mg/L limit.

The result of the reactive sulfides test performed by ACZ on the blended LANL waste was 0.3 mg/kg. The result for the Fernald waste was significantly higher at 52 mg/kg. The Fernald waste also had a higher pH because it received more of the proprietary sulfiding liquid, which has a high pH. A larger amount of this liquid would also result in a higher reactive sulfide value. However, both waste streams were still well below the limit of 500 mg/kg and neither requires further treatment for reactive sulfides. Table 2 gives the results of the analytical tests for both waste streams.

Table 2. Mixed waste treatment results (Utah-certified laboratory).

Analytical Test	LANL Waste Results	Fernald Waste Results
Mercury (TCLP)	0.048 mg/L	0.0349 mg/L
Free liquid by paint filter	No free liquid	No free liquid
pH, Saturated paste	8.2	11.9
Solids, percent	90.9%	88.7%
Cyanide, total	Nondetectable	Nondetectable
Sulfide, reactive	0.3 mg/kg	52 mg/kg
Alpha	1.43 pCi/g	0.26 pCi/g
Beta	0.71 pCi/g	0.04 pCi/g
Potassium-40	0.48 pCi/g	0.062 pCi/g

Degree to Which the Process Meets the TDRD

The ADA process performed well in meeting the requirements set forth in the MWFA TDRD. Table 3 lists the requirements as they appear in the TDRD and assesses ADA's efforts to meet them.

Table 3. Performance with respect to TDRD[a] requirements.

Specific TDRD requirement	ADA amalgamation technology demonstration results
1.1.1 Pretreatment methods	No pretreatment was required for either the waste or the treatment materials. However, for debris or other mercury contaminated wastes, some pretreatment steps may be required.
1.1.2 Process mechanism	Small pug mill unit with a dual-shaft mixer (0.06-m^3 capacity) 0.9 m long by 0.1 m^2 cross-section, having 14-cm-long mixing blades with overlap for more efficient mixing. Liner reduces dead volume. Typical rotational speed is 50 rpm. This size unit achieves the desired full-scale processing rate of 40 kg of mercury per shift (8 hours).
1.1.3 Particle size	Particle size of sulfur used in treatability tests was 80–100 µm. Additive used to facilitate the amalgamation reaction was in a liquid form.
1.1.4 Control of free mercury in final waste	Treatment process effectively removed free mercury. No special controls were needed to reduce free mercury in the final waste.
1.1.5 Optimal waste loading	Treatability study and surrogate test results both indicate that the optimum waste loading is between 50 and 60%.
1.1.6 Final waste form	Final waste form passes TCLP and can be disposed of in a RCRA 40 CFR 264.301, Subtitle D, facility. Treatability-study TCLP results were 0.048 mg/L for LANL waste and 0.035 mg/L for Fernald waste,[b] well below the limit of 0.20 mg/L mercury.
1.1.7 Amalgamation process	Process uses inexpensive treatment materials (sulfur) and a small amount of an inexpensive liquid (proprietary). Process uses no precious metals.
1.1.8 Effect of contaminants	Effect of contaminants was determined for water, small amounts of which, such as 10% by volume, pose no problem to the process. Larger amounts were not tested. The major effects of water are matrix cooling and reaction slowing, retarding the formation of HgS. ADA expects that small amounts of chlorine, nitrates, sodium, and vacuum pump oil are not likely to impact the process.
3.1.1 Definition of amalgamation	Process utilizes sulfur to convert elemental mercury to mercury sulfide, which satisfies the definition of amalgamation in RCRA 40 CFR 268.42, Table 1.
3.1.2 Amalgam waste loading	Mercury waste loading (treatability study) was ~57% (TDRD requirement is 50%). Optimal waste loadings are 50–60%.
3.1.3 Formation of mercuric oxide	Processing was performed without adding heat. Reaction is exothermic at room temperature; mixture increases in temperature during processing. Formation of mercuric oxide was not a concern due to the low processing temperature.
3.1.4 Formation of mercury vapor	Processing was performed in ambient conditions. Mercury vapor concentrations above the pug mill were below the Threshold Limiting Value (TLV) of 0.05 mg/m^3. Operators could monitor mixing and add reagents as required without any special precautions, although all operators wore respirators fitted with cartridges designed to remove mercury vapor.
3.1.5 Secondary waste streams	Minimal secondary waste created falls into three categories: personal protection equipment (PPE), decontamination materials, and filters. Estimates are as follows (for full-scale treatment): sand as 1–5% or nitric acid wash as <0.1% (of the total volume of stabilized waste); PPE, gloves, etc., at 0.5 ft^3 per day; and filters at 2.0 ft^3 per year.
3.1.6 Free elemental mercury in the final waste	Extents of reaction for five batches treated were 99.93, 99.92, 99.87, 99.94, and 99.98%, respectively, corresponding to free mercury values of 0.07, 0.08, 0.13, and 0.02%, all of which were well below the 4.5% upper limit.

Specific TDRD requirement	ADA amalgamation technology demonstration results
3.1.7 Decomposition of final waste	Treated waste was not tested for decomposition stability at elevated temperatures or in a range of different pH values at ADA. These tests will be performed at ORNL and reported with the results on NFS samples.
3.2.1 Process temperature	Processing is conducted in ambient environmental conditions. Mercury vapor concentrations above the mill were below the Threshold Limiting Value (TLV) of 0.05 mg/m^3.
3.2.2 Control of mercury vapor	Temperature was monitored during processing. Room air was swept over the pug mill to remove vapors and then filtered through a HEPA filter and passed through a sulfur-impregnated carbon filter to capture the mercury.
3.2.3 High radiation dose rates	Per TDRD, this criterion is typically not a consideration with this waste type.
3.2.4 Moisture	The presence of small amounts of water (upwards of 10% by volume) in the mercury waste is not a problem.
3.3 Throughput	The mill used would accommodate full-scale processing rate of 40 kg (88 lb) mercury in an 8-hour shift. A full-scale pug mill would be able to handle even larger throughputs, beyond the 100-lb per 8-hour shift TDRD requirement.
3.4 Duty cycle	Process is designed to operate on an 8-hour shift, 5 days per week.
3.5 Reliability	The mill used is commercially available and is proven reliable for industrial use. Such mills have been used in large-scale soil treatment applications. The demonstrated unit operated efficiently for all batches, producing similar products with consistent TCLP leach performance.
3.6 Maintainability	Minimal maintenance and personnel exposure seen during routine operations. Worker effort and secondary waste stream generation during decontamination of the pug mill are also minimal.
3.7 Ambient conditions	Processing is performed in ambient environmental conditions.
3.8 Transport-ability	A mobile treatment unit could be fabricated to treat at specific sites. The pug mill is small enough to fit in a large truck along with the support equipment. The minimal utility requirements of the system make it an ideal candidate for mobile treatment. The cost for such a unit has not been developed at this time.
3.9 Physical characteristics	After processing, waste is returned to the original shipping container and packaged in accordance with transportation and disposal requirements. Treated waste has a measured bulk density of 1.78 g/cm^3 (110 lb/ft^3) and so will occupy 7.2 ft^3 at the maximum weight of 800 lb (for a 55-gal drum). Fill material is added to the container to meet the 90%-full requirement.
3.10 Waste acceptance	Treated waste forms meet current Envirocare WAC for disposal, including TCLP, reactive sulfide, reactive cyanide, paint filter test, etc.
4.0 Key regulatory and safety requirements	A hazard evaluation was prepared at the start of the treatability study. No additional hazards or safety occurrences were encountered during operation. Hazards associated with the process are similar to those encountered in small-scale waste cementation processes.
5.0 Schedule needs	Process could be used to treat waste as early as January 1999 from an equipment or process standpoint. ADA does not perform treatment at its site, so a treatment site that has a RCRA Part B permit must be used.
6.0 Public and	The public is generally in favor of this approach (see Section 6).

Specific TDRD requirement	ADA amalgamation technology demonstration results
tribal involvement	
7.0 Quality assurance and testing	The work performed under the treatability study was performed according to the written quality assurance plan (QAP). The test plan and the QAP were both approved by the MWFA before the waste was treated.
8.0 Disposition of equipment and waste	Worker effort and secondary waste stream generation during decontamination are minimal. Sand and nitric acid aid decontamination and can either be added to the bulk amalgamated material (since sand is an additive in the amalgamation procedure) or be disposed of separately as a low-level waste that passes TCLP. Nitric acid can be reduced in volume by evaporation, neutralized, and disposed of as a low-level waste. In all cases, decontamination results in a small amount of waste that will pass the TCLP for mercury.

[a]*The applicable Technology Deficiency Requirements Document (TDRD) is that for mercury amalgamation, July 30, 1996, Revision 0.*

[b]*Two waste streams were treated by ADA in this demonstration: one from Los Alamos National Laboratory (LANL) in Albuquerque, New Mexico, and one from the Fernald site in Fernald, Ohio.*

SECTION 4

TECHNOLOGY APPLICABILITY ALTERNATIVES

Competing Technologies

Baseline Technologies

RCRA regulations call for amalgamation of elemental mercury waste that cannot be recycled; this category includes radioactive elemental mercury. Hence, amalgamation is the baseline process for treatment of elemental mercury waste. Amalgamation is the process of alloying mercury with another metal, such as zinc, copper, nickel, gold, or sulfur, to form a combination that is solid at room temperature. In waste treatment, the objective of amalgamation is the stabilization of mercury for subsequent separation or disposal. The primary type of waste that requires amalgamation is free elemental mercury, although a few waste streams with treatability matrix parameters of debris and soil have been slated for amalgamation treatment by DOE sites.

Mercury amalgamation has been used throughout modern history to extract precious metals (e.g., gold, silver) from metal ore. RCRA regulations impose requirements for the final waste form, which must also be met through adherence to the Universal Treatment Standard (UTS) or a defined technology-based treatment standard. Only in the relatively small-scale dental applications are there commercial uses of amalgamation technology to produce waste forms with requirements similar to those in waste management.

Various treatability studies and other development efforts performed throughout the DOE complex have explored the ability of several different materials to stabilize mercury, including tin, zinc, copper, sulfur, and sulfur polymer cement (SPC). However, until this demonstration, known investigations on mixed waste amalgamation were limited to bench scale. Hence, there is no commercial-scale technology available to serve as a baseline.

Other Competing Technologies

A *Commerce Business Daily* (CBD) announcement (Request For Information) by the HgWG on mercury treatment technology capabilities produced 42 responses. Among the respondents, all of whom received the subsequent RFPs, only two proposals pertained to amalgamation. The RFP responses may be taken as a major indicator of existing capabilities across the nation and of vendors desiring to prove their technology. Both bids were found to be acceptable by the HgWG, based on its pass/fail criteria (Simpson 1996). From these two bids, demonstration contracts were put in place with the respective vendors: one to ADA for its process and another to Nuclear Fuel Services, Inc. (NFS, Erwin, Tennessee). Hence, the NFS process is seen as the only one competing with that of ADA. As there is no appropriate baseline, these two competing technologies will be compared.

ADA proposed a process for stabilizing radioactively contaminated elemental mercury with sulfur. The process combines a proven mercury stabilization method with a scalable, economically viable mixing technology. In the ADA process, waste mercury is mixed with sulfur in a commercially available pug mill, producing a stable mercury sulfide product. The pug mill is well-suited to the process because of its ability to adequately mix the components and control the residence time to ensure complete reaction. In addition, radioactive contamination control requirements, necessary for dealing with mixed waste, can be readily implemented using the pug mill.

The findings from the NFS demonstration are reported in detail in a separate Innovative Technology Summary Report (ITSR). The product from the NFS demonstration passed TCLP treatment standards and met vapor pressure requirements (during processing) described in the TDRD. In addition, the NFS process was able to meet the UTS (0.025 mg/L) for many of its waste forms. The process also satisfies the EPA's definition of an amalgam as given in 40 CFR 268.42, Table 1, satisfying disposal requirements as outlined in RCRA regulations.

Technology Comparison

The comparison of the ADA process with the competing amalgamation process technology demonstrated by NFS is shown in Table 4. In general, applications of the NFS process will require a two-step version of the process: amalgamation plus further stabilization. An important limiting factor is the high cost. Although, the NFS process is estimated to cost less than the ADA process, the cost is nevertheless high. However, treatment prices could be improved if larger quantities of waste were to be treated at a central location.

Technology Applicability

The ADA process is specifically suited to the treatment of elemental mercury waste and the secondary waste streams of elemental mercury produced from thermal systems used to treat mercury-contaminated wastes. However, the process may also be applicable to other mixed waste streams containing mercury, although additional treatment steps and further testing may be required. For the possible application of ADA's process to wastes other than elemental mercury, the following must be considered:

- how effectively can the matrix be sorted and/ or shredded to promote contact between the sulfur and the mercury,
- what are the metals co-contaminants of concern particularly those that are also a RCRA concern and will compete for the sulfur, and
- what will be the effect on the amalgamation/ stabilization of mercury in the presence of a significant organic content?

In the course of this demonstration, ADA has shown that its amalgamation process should be sufficiently robust to address elemental mercury wastes at DOE sites with various chemistries. Specimens of radioactively contaminated elemental mercury mixed wastes derived from both DOE sites (LANL and Fernald) have been successfully treated (see Table 2). The process can generally achieve waste forms meeting the Land Disposal Restrictions (LDR) criteria with projected processing rates exceeding the minimum specified by the MWFA.

The size of pug mill used in the treatability study would accommodate a full-scale processing rate of 40 kg (88 lb) of mercury in an 8-hour shift with no difficulty. A full-scale pug mill would be able to handle larger throughputs, beyond the 100-lb minimum listed in the TDRD. The size of the batches treated is dependent upon the size of the mill used.

Table 4. Comparison of ADA and Nuclear Fuel Services, Inc. (NFS), amalgamation technologies.

Comparison factor	NFS	ADA
Pretreatment methods	None for elemental mercury.	None for elemental mercury.
Process mechanism	Standard laboratory glassware operation based in a ventilation hood	Pug mill, a dual-shaft mixer, with liner to decrease dead volume
Particle size of the amalgamating material	Processes are similar in this regard. Particle sizes are on the order of 50–100 microns	
Control of free mercury in the final waste	Both forms eliminated free mercury in the final waste	
Optimal waste loading	20–25%[a]	50–60%
Final waste form	Passes TCLP and, largely, UTS	Passes TCLP
Amalgamation process	Uses proprietary additives and EPA-prescribed agents	Uses sulfur and a small amount of proprietary liquid
Effect of contaminants on the process	Tolerated oily phase in Hg	Water <10% tolerated. Other contamination not addressed
Definition of amalgamation	Both processes meet the definition of amalgamation	
Amalgam waste loading	20–25%[a] achieved	57% achieved in demonstration
Formation of mercuric oxide Formation of mercury vapor	Both processes employ low (ambient) operating temperatures and were easily able to meet OSHA requirements, minimizing these concerns	
Secondary waste streams	Bottles, solutions, gloves, tissues, rags, and lab coats are 15% of final waste form	Sand, PPE, decontamination materials, and filters amount to about 5% of stabilized waste
Decomposition of final waste	Being evaluated at ORNL	Being evaluated at ORNL
Ambient environmental conditions Process temperature	Both processes are operated at ambient conditions	
Control of mercury vapor	Process operated in a ventilated hood	Forced convection of room air through a HEPA filter
Moisture	Moisture (water in small amounts) is tolerated by both processes	
Throughput	80 kg/8 hours at full scale	>100 kg/8 hours at full scale
Duty cycle	Both processes designed to operate an 8-hour shift, 5 days/week	
Reliability Maintainability	Both processes use commercially available equipment and proprietary reagents. Demonstrated reliability and maintainability are similar.	
Transportability	Both processes could be deployed as mobile units. Equipment is small enough to fit in a truck. Minimal utility requirements	
Physical characteristics	Waste form characteristics are physically similar	
Waste acceptance criteria	Both processes produce waste forms that meet current Envirocare Waste Acceptance Criteria (WAC)	
Regulatory and safety requirements	No additional hazards, safety, or regulatory issues found for either process	
Public and tribal involvement	The processes are identical in this respect	
Quality assurance and testing	Both processes were demonstrated according to a MWFA approved Quality Assurance Plan (QAP)	
Disposition of equipment and waste	Both processes are similar in this regard	
Estimated cost (for 1,000–1,500 kg)	Slightly lower than ADA's but volume considerations are key	Slightly higher than NFS' but volume considerations are key

Comparison factor	NFS	ADA
Summary assessment	Less costly, better leach performance (in being able to meet UTS)	Higher waste loadings, less secondary waste, and fewer proprietary reagents

[a] NFS stated an exception to this criterion that the loading of mercury in its bulk elemental mercury amalgamation process was in the 20 to 25 wt% range based on performance criteria needed for LDR.

SECTION 5

COST

Methodology

Capital equipment and operational costs for a full-scale facility were evaluated as part of this study to determine the treatment cost for the process. A full-time treatment evaluation was based on a facility designed to treat 624 L of waste mercury per year. Present-value life-cycle costs were determined for a facility of this size operating over a 5-year period. Treatment costs for secondary wastes and costs for preparing wastes and residues for disposal were included in this evaluation. Waste transportation and disposal costs are included in the present-value life-cycle cost for this facility. Also included are costs for using a treatment site that has a RCRA Part B permit.

Mixing equipment for a full-scale operation will be large enough to process 3 L of mercury in 40-kg batches. This batch size would be required in order to process 624 L of waste mercury per year. Other equipment would also be needed to support the operation, including safety equipment such as radiation and mercury monitors, eyewash/shower station, and scales to weigh process materials and drums with treated waste. Laboratory equipment would also be required to perform analytical procedures during the waste processing operation.

The costs associated with the installation of the process equipment and process materials such as piping and ductwork, electrical, insulation, process structural, and instrumentation were not directly determined, but estimated using a method presented by Perry's *Chemical Engineer's Handbook* (Perry and Chilton 1973). The method uses average percentages for direct and indirect construction costs based on data from more than 200 chemical process capital projects. On average, the process equipment and process materials costs were found to be 33 and 16% of the total installed facility cost, respectively. Labor for process equipment and materials installation was about 13% of installed costs.

Annual maintenance costs were also estimated using recommendations by Perry, which suggests that the maintenance cost can be based on a fixed percentage of the capital equipment costs. Capital equipment included the process equipment and process materials. In general, maintenance should be a minimum of 4% per year of the capital equipment cost for chemical processing equipment. Maintenance costs would include the material, labor, and overhead costs.

Labor costs were estimated based on a three-person staff. The staff would be required to perform the operational, analytical, and clerical functions associated with the process. Direct labor, materials and supplies, and subcontracted analytical costs, as well as the indirect costs, were included in the operating costs for this process. Materials and supplies were determined on a per-batch basis, which assumed the facility would treat 15 waste streams per year, each consisting of 42 L of mercury. The mercury would be processed in 3-L batches, for a total of 210 batches per year. The annual analytical costs were determined based on the number of waste streams. These costs included characterization tests of the wastes to document that the waste passed TCLP for mercury, as well as swipe tests to certify cleanliness of the process equipment.

Operating costs for the process were escalated at a rate of 3.5% per year over the life of the project. The present value of each year's operating costs was totaled and added to the construction costs of the facility for the overall present value of life-cycle costs. The cost of using a treatment site is also included. Treatment costs for 500, 1,000, and 1,500 kg were determined two ways. The first method was based upon a total treatment volume of either 500, 1,000, or 1,500 kg. This is, by far, the most expensive way to treat waste since the capital cost of the equipment is spread out over a very small amount of waste. Also, the technology use fee will be higher on a per-kilogram basis for small amounts of mercury.

The second method for evaluating costs assessed the cost of treating 500, 1,000, or 1,500 kg as part of a full-time treatment process based upon a life cycle of 5 years. This was less expensive since the cost of the capital equipment was spread out over much more waste, and the technology use fee was proportionally lower. The cost associated with the use of a site that has all required permits was based upon a yearly use cost divided by the mass treated in a full-time operation. This number was used in both scenarios since it would be very difficult and expensive to set up a treatment facility for 10–25 days, which is the amount of time required to treat the 500–1,500 kg.

Cost Conclusions

In prior efforts, the HgWG has found that the major obstacle to deploying mercury-treatment technologies is the small quantities of most waste types at a given site. A single technology capable of treating most of the streams would be prohibitively expensive to deploy. Cost estimates for treatment of wastes from a single site at an offsite vendor are also seen to be extremely high. These findings are true for amalgamation based on information and costs estimates supplied by ADA and NFS. For this reason, national contracts combining the wastes of a given type from the DOE complex under a single treatment contract offer a rational, cost-effective approach to treatment technology deployment. The HgWG has planned a national contract for treatment of elemental mercury waste. Further information about national contract planning by the HgWG is provided in Appendix B. To avoid jeopardizing this national initiative, the exact vendor cost figures will not be published in this report. However, both vendors indicated that if either were to be contracted to treat over 1,500 kg of elemental mercury, the cost would be approximately $300/kg. This estimate assumes that the waste is elemental mercury that can be treated in one large production run without interim system decontamination requirements. Disposal costs of the treated waste are not included in the estimate. The treatment of mercury wastes requiring amalgamation will be very expensive, unless additional economies of scale can be capitalized on. Larger-scale processing operations, such as a centralized facility, will tend to be favored economically over multiple smaller, site-based operations.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

The regulatory/permitting issues related to the use of amalgamation technology are governed by the following safety and health regulations:

- Occupational Safety and Health Administration (OSHA), 29 CFR 1926

- 1926.28	Personal Protective Equipment
- 1926.102	Eye and Face Protection
- 1926.103	Respiratory Protection

- OSHA 29 CFR 1910

- 1910.132	General Requirements (Personnel Protective Equipment)
- 1910.133	Eye and Face Protection
- 1910.134	Respiratory Protection.

Disposal requirements/criteria include the following DOT and DOE requirements:

- 49 CFR, Subchapter C, Hazardous Materials Regulation

—171	General Information, Regulations, and Definitions
—172	Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements
—173	Shippers—General Requirements for Shipments and Packagings
—174	Carriage by Rail
—177	Carriage by Public Highway
—178	Specifications for Packaging

- 10 CFR 71 Packaging and Transportation of Radioactive Material.

If the waste is determined to be hazardous solid waste, the following EPA requirement should be considered:

- 40 CFR, Subchapter 1 Solid Waste.

CERCLA Criteria

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) has established nine criteria against which alternative treatment approaches are to be judged during the Remedial Investigation/ Feasibility Study (RI/ FS) portion of the remediation action. A short explanation of each of the criteria (EPA 1988) and the assessment of ADA's process against it follow.

<u>Overall protection of human health and the environment</u>

This criterion is an evaluation of the overall protectiveness of an alternative. It focuses on whether a specific alternative achieves adequate protection and describes how site risks posed through each pathway being addressed by the FS are eliminated, reduced, or controlled.

In a CERCLA environment, the resulting waste forms from the ADA process will provide improved protection of human health and the environment by reducing the mobility of the elemental mercury. The amalgams should be placed inside another container to further enhance protection.

Compliance with ARARs
This evaluation criterion is used to determine whether each alternative will meet all of its federal and state Applicable or Relevant and Appropriate Requirements (ARARs) that have been identified in previous stages of the RI/ FS process.

The Land Disposal Restrictions are the most likely ARAR to be applied to a CERCLA site dealing with elemental mercury. These regulations under RCRA specify amalgamation for elemental mercury. ADA's process meets that definition.

Long-term effectiveness and permanence
Alternatives under this criterion are to be evaluated in terms of risk remaining at the site after response objectives have been met. The primary focus of this evaluation is the extent and effectiveness of the controls that may be required to manage the risk posed by treatment residuals and/ or untreated wastes.

The long-term effectiveness of any remediation process has to be judged not only by the efficacy of the actual treatment process but by how well the process can be applied to the extent of the contamination. Assuming that the elemental mercury can be efficiently brought to ADA's equipment, the process should be able to provide environmental protectiveness. Tests to be performed at ORNL will provide a more definitive answer.

Reduction of toxicity, mobility, or volume through treatment
The statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances are to be evaluated under this criterion.

Amalgamation using sulfur should significantly reduce mercury's mobility in a waste management scenario. In a CERCLA action, further study would be required to assess how the action of bacteria affects the waste form. Secondary containment may be prudent in any case.

Short-term effectiveness
This criterion addresses the effects of the alternative during the construction and implementation phase until remedial response objectives are met.

As designed and operated at CMRI, the ADA process should be protective of the community and the workers while not imposing meaningful environmental consequences during its operation.

Implementability
The implementability criterion focuses on the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during implementation.

The process should prove to be viable from the standpoints of both the technical (ability to construct, reliability, and monitoring) and administrative (coordination with other agencies) feasibility as well as the availability of services and materials.

Cost
The costing procedures found in the *Remedial Action Costing Procedures Manual* are to be the bases for comparing alternatives with regard to costs.

The cost figures to be provided in the future were not based on the rigor detailed in the referenced document above.

State acceptance
This assessment evaluates the technical and administrative issues and concerns the state (or support agency in the case of state-lead sites) may have regarding each of the alternatives.

See "Safety, Risks, Benefits, and Community Reaction" subsection below.

Community Acceptance

Under this criterion, an assessment is made on the issues and concerns the public may have regarding each of the alternatives.

See “Safety, Risks, Benefits, and Community Reaction” subsection below.

Safety, Risks, Benefits, and Community Reaction

ADA prepared a hazard evaluation at the start of the project (ADA 1998, see Appendix B). No additional hazards or safety anomalies were encountered by ADA during the course of the demonstration. In general, ADA found that the hazards associated with the process are similar to those encountered in small-scale waste cementation processes. Other aspects of risk were evaluated by the HgWG, considering eight criteria for the level of risk as associated with mercury amalgamation, as follows:

1. correctness (technical correctness),
2. cost (effectiveness to use),
3. permitability (ease of permitting),
4. safety,
5. sponsorship (commitment by sponsors),
6. completeness (ready for use),
7. acceptability (to stakeholders), and
8. timeliness (to meet schedules).

The risk values, established for the MWFA developed technology processes, have been derived from top-level requirements defined in the MWFA Systems Requirements Document. Evaluations of the technology and assignment of risk values were made by a team comprised of HgWG members, in consideration of the risk category definitions and performance observations from the demonstration experience. The assessments made are summarized below.

Correctness

This risk category is rated as very low. The targeted volume of waste to be treated is small compared with most other waste types. The fact that amalgamation is required by law reflects the fact that this type of technology is appropriate for this waste. The performance demonstrated by ADA adequately addresses any concerns over the capability of their process to successfully treat mercury mixed waste.

Cost

This risk category is rated as moderate. The targeted volume to be treated is low, but the waste possesses diverse characteristics. Oxidation, complexation, and speciation of mercury across various matrices add an element of uncertainty as to the difficulty of successfully stabilizing the bulk of inventory (and future generation) without process modifications. In addition, cost estimates provided by ADA are characterized by some uncertainty.

Permitability

This risk category is rated as very low. The treatment process is simple and based on a well-proven Best Demonstrated Available Technology for nonradioactive mercury waste. The volumes of waste involved are small enough to pose little likelihood of regulatory problems.

Safety

This risk category is rated as low. While mercury is a hazardous material of some concern and radioactive contamination has the potential to raise additional concern, mercury vapors and leaching appear to be well controlled by the process and radioactive contamination is low. The stability of the final waste form is key in immobilizing both mercury and radionuclides, thereby minimizing concerns over worker safety, public safety, and environmental protection.

Sponsorship

This risk category is rated as moderately low. Interest by the sites has been good, and programmatic support for technology development has demonstrated good commitment. There is a small risk that some potential users may find a local or onsite solution for treatment of their mercury wastes.

Completeness

This risk category is rated as moderately low due to the simple, proven nature of amalgamation, in consideration of the potential complexity of mercury chemistry and diversity of waste matrices.

Acceptability

This risk category is rated as very low. Amalgamation is a process easily identifiable to the public because of its long-time use by the dental profession. The waste form stability, simplicity, and small-scale nature that characterize the technology are expected to make gaining public acceptance easy.

Timeliness

This risk category is rated low. Based on preliminary information received to date from 10 DOE sites, the timeframe for treatment is late FY-99 and FY-00. If a national contract is put in place, all sites will have a path forward to disposal for their mercury wastes requiring amalgamation, via a single vendor under contract.

Public Participation

The siting of a mixed waste treatment facility of any kind near communities will involve public input. Stakeholders are generally concerned about the type, toxicity, and amount of emissions to be discharged to the atmosphere and the disposal site for the final waste form.

The MWFA Tribal and Public Involvement Resource Team and HgWG initiated activities to involve and gather stakeholder issues, needs, and concerns about mercury treatment technologies. These activities included reviews, articles, and presentations. During November and December of 1997, the chair of the HgWG addressed both the Oak Ridge Local Oversight Committee and the Site Specific Advisory Board (SSAB). The purpose of the November 17–18, 1997 meetings was to identify issues, needs, and concerns of various Oak Ridge stakeholders regarding technologies that may be applicable to Oak Ridge. The areas emphasized included continuous emission monitors, characterization, input to Technology Performance Reports, and the HgWG. These meetings were interactive, where participants explored the issues and problem-solved collectively. No formal presentations were made, but information was provided and progress on various MWFA projects was discussed. Participants included members of the local oversight committee, the Site Technology Coordination Group (STCG), and the general public.

The SSAB Environmental Technology Group meeting on December 10, 1997 involved providing stakeholder input into various technology development projects at Oak Ridge. Those they have expressed interest in addressing are:

- Transportable Vitrification System
- TSCA Test Bed for Continuous Emissions Monitors
- Mercury Working Group/Mercury Treatment Demonstrations
- Removal of Mercury from Liquid Wastes

A short presentation on the status of each activity was given and the proposed future scopes were discussed.

The MWFA assembled a Technical Requirements Working Group (TRWG); a stakeholder group capable of representing varied Tribal and public perspectives. The TRWG assisted MWFA technical staff in transforming or integrating site-specific issues, needs, and concerns into the Technology Development Requirements Documents (TDRDs), and providing Tribal and public perspectives to technical staff for identifying and resolving technical issues. The TRWG reviewed and provided recommendations to the MWFA on changes to the Mercury Amalgamation TDRD.

Lastly, the MWFA Resource Team facilitated tribal and public involvement by issuing an article in the quarterly, July 1997, newsletter highlighting mercury treatment and disposal.

The plan for a national contract for mercury waste treatment is consistent with minimizing concerns over siting for what would otherwise be multiple treatment facilities. While there are still transportation issues, these are expected to be routine and present no special concerns. No tribal issues are anticipated.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The “lessons learned” from this process showed no surprises in waste handling or processing conditions required to adequately treat the waste.

Technology Limitations and Needs for Future Development

The high cost of treatment indicates a need for cost reduction measures, such as can be gained through the implementation of a national procurement contract.

Some unknowns still exist that pertain to the effect of contaminants in commercial-scale amalgamation of mercury-contaminated mixed wastes. The effect of speciation has also been little explored. Available information is limited, and further investigation is needed.

Technology Selection Considerations

The process as demonstrated works well on elemental mercury. When the process is located at a facility with a RCRA Part B permit, the primary consideration will be the extent of contamination of both RCRA substances and radionuclides.

APPENDIX A

References

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APPENDIX B

NATIONAL TREATMENT CONTRACTS

With projected treatment costs on the order of $300/kg or more, the treatment of mercury wastes requiring amalgamation will be very expensive unless additional economies of scale can be capitalized upon. Larger-scale processing operations, such as a centralized facility, will tend to be favored economically over multiple smaller, site-based operations. The national treatment contract initiatives proposed by the MWFA/ HgWG offer a route to more economical unit treatment costs.

National Treatment Initiatives

In the HgWGs efforts to better define the mercury waste problem across the DOE complex, the HgWG has found that the major obstacle to deploying mercury-treatment technologies is the small quantities of most waste types at a given site. A single technology capable of treating most of the streams would be prohibitively expensive to deploy. Cost estimates for treatment of wastes from a single site at an offsite vendor are also seen to be extremely high. For this reason, national contracts combining the wastes of a given type from the DOE complex under a single treatment contract seemed the most rational, cost-effective approach.

HgWG investigations into commercial treatment costs revealed six main cost categories, which are as follow: (1) procurement, (2) characterization, (3) packaging, (4) shipping, (5) treatment, and (6) final disposal. Considering each of these categories in turn, characterization, packaging, and shipping costs will vary only slightly depending on how the wastes are treated.

The remaining three categories of procurement, treatment, and final disposal can change costs dramatically if national contracts are used. Procurement costs are essentially constant, regardless of the size of the waste stream involved. Such costs for multiple sites can be reduced substantially if a national contract is in place. Treatment costs are more complex and typically have a fixed portion and a variable portion. Both treatment and disposal costs have economies of scale. For example, the Oak Ridge contract for waste disposal at Envirocare sets a $20,000 minimum fee for each waste stream, with increasing costs beyond a threshold quantity. A national contract with Envirocare allowing the combination of small streams from different sites would result in substantial savings, on the order of $20,000 per stream combined. The current contract with DOE- Oak Ridge contains a specific provision that "DOE shall not mix or otherwise combine the waste material with any other material or products from any other waste stream of one generator or generating site with that of another generator or generating site, nor present the same for disposal by the Contractor." How Envirocare would view the commingling of DOE wastes at a vendor's facility must be explored. Various site representatives have demonstrated significant interest in combining streams to achieve such savings for mercury and other waste streams.

Planned Contracts

Because of widely varying matrices, several different treatment processes are required to treat DOE mercury mixed wastes. The EPA specifies required treatments for the different types of mercury wastes. For example, elemental mercury must be amalgamated. Solid matrices, other than debris, with total mercury concentrations less than 260 ppm must be stabilized. Inorganic matrices (soils, sludges) with greater than 260 ppm mercury must be retorted or roasted. Matrices with organic compounds present must be incinerated. Debris can be macroencapsulated to meet the EPA treatment standard. Alternate technologies may also be available to treat the >260 ppm wastes, depending on what planned MWFA HgWG demonstrations can achieve.

Current MWFA planning will ensure that national contracts are in place to treat all of the different types of waste. The national contracts currently planned by the HgWG are summarized in Table B.1.

Table B.1. Summary of national contracts planned by the Mercury Working Group (HgWG).

Waste Type	Contract
Elemental mercury	MWFA national contract
Less than 260 ppm sludges and soils	Army Industrial Operations Command Contract; Oakland DOE Contract
Greater than 260 ppm sludges and soils	Balance of Inventory Procurement (BOIP) with HgWG
Debris	Army Industrial Operations Command Contract; Oakland DOE Contract
Mercury with PCBs	BOIP with HgWG
PCBs	BOIP with HgWG

Status of Planned Contracts for Elemental Mercury

The MWFA plans to establish a contract in fiscal year (FY) 1998 through which all DOE sites across the nation can treat their elemental mercury during FY 1999 and FY 2000. The BOIP, also know as the Broad Spectrum procurement, currently does not provide for amalgamation of elemental mercury streams and, because these wastes are well defined, the MWFA will proceed with placing that contract through the HgWG. The HgWG is currently collecting the following information from the sites:

- quantity of elemental mercury,
- state of characterization,
- amount of site funding availability for packaging, shipment, treatment, and disposal;
- milestones driving treatment, and
- letter of commitment from site indicating its intention to participate.

Upon completion of data collection, the HgWG will establish a contract based on the amount of elemental mercury committed to by sites. The MWFA will then notify the sites of the schedule for shipping and treating waste, allowing time for waste characterization and repackaging. The MWFA and HgWG will track the progress of waste shipments, treatment, and disposal.

The National Strategic Materials Stockpile program has indicated an interest in participating in the amalgamation contract. A representative of the program has offered to include enough of the stockpile mercury to get the price incentive for volume.

APPENDIX C

ACRONYMS

ADA	ADA Technologies (Englewood, Colorado)
ARARs	Applicable or Relevant and Appropriate Requirements
BOIP	Balance of Inventory Procurement (i.e., Broad Spectrum Procurement)
CBD	*Commerce Business Daily*
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMRI	Colorado Minerals Research Institute
DeHg	A proprietary process by NFS for processing mercury mixed waste (pronounced de´-merk)
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
HgWG	Mercury Working Group, MWFA
INEEL	Idaho National Engineering and Environmental Laboratory
ITSR	Innovative Technology Summary Report
LANL	Los Alamos National Laboratory
LDR	Land Disposal Restrictions
LESAT	Lockheed Environmental Systems and Technologies Company
MER01	A solicitation to industry (November 1996) entitled, "Demonstration of the Amalgamation Process for Treatment of Radioactively Contaminated Elemental Mercury Wastes"
MWFA	Mixed Waste Focus Area
NFS	Nuclear Fuel Services, Incorporated (Erwin, Tennessee)
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PPE	personal protection equipment
Ppm	parts per million
QAP	Quality Assurance Plan
RCRA	Resource Conservation and Recovery Act
RFP	Request for Proposal
RI/ FS	Remedial Investigation/ Feasibility Study
SPC	sulfur polymer cement
STCG	Site Technology Coordination Group
TCLP	Toxicity Characteristic Leaching Procedure
TDRD	Technology Development Requirements Document
TLV	Threshold Limit Value
UTS	Universal Treatment Standard
WAC	Waste Acceptance Criteria