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ARI Technologies Asbestos Destruction

National Energy Technology Laboratory (NETL)

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INNOVATIVE TECHNOLOGY
Summary Report

ARI Technologies Asbestos Destruction

Tech ID 3114

National Energy Technology Laboratory (NETL)

Demonstrated at:
ARI Technologies' Facility.
Tacoma, Washington
(Asbestos Waste from Savannah River Site, Aiken, SC)

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 whether 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 www.em.doe.gov/ost under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Waste asbestos from abatement activities at Department of Energy (DOE) facilities is typically (as is most asbestos waste in the United States) disposed of in landfills. However, some of the asbestos from DOE facilities is contaminated with radionuclides, PCBs, RCRA metals and perhaps other regulated components, which may require pre-treatment prior to landfill disposal. Landfilling of waste is becoming less desirable to the public and does nothing to reduce the toxicity or the continued liability associated with these wastes. Methods for permanent destruction of these wastes are becoming more attractive as a final solution. One of the methods available to the DOE for the destruction of asbestos-containing wastes is thermochemical conversion technology.

How it Works

Thermochemical conversion technology (TCCT), pictured in Figure 1 below, uses a combination of chemical treatment and heat to cause remineralization of asbestos and other silicate materials. The remineralization process accomplishes several goals including:

- Conversion of asbestos minerals into non-asbestos minerals without melting
- Destruction of organic compounds through pyrolysis and/or oxidation
- Immobilization of metals and radionuclides

The process involves shredding and then mixing asbestos-containing material (ACM) with proprietary fluxing agents and heating the fluxed mixture. The presence of the fluxing agents at elevated temperatures (approximately 2200°F) results in the rapid remineralization of asbestos fibers. The process also results in the destruction of organics, including PCBs to 99.9999 percent destruction removal efficiency. Toxic metals are stabilized in the sintered product through molecular bonding and the technology developer believes the process will also be effective for radionuclides, based on preliminary Product Consistency Testing (PCT). The processing equipment consists of four primary systems including feed preparation, rotary hearth converter, off-gas treatment, and product removal.

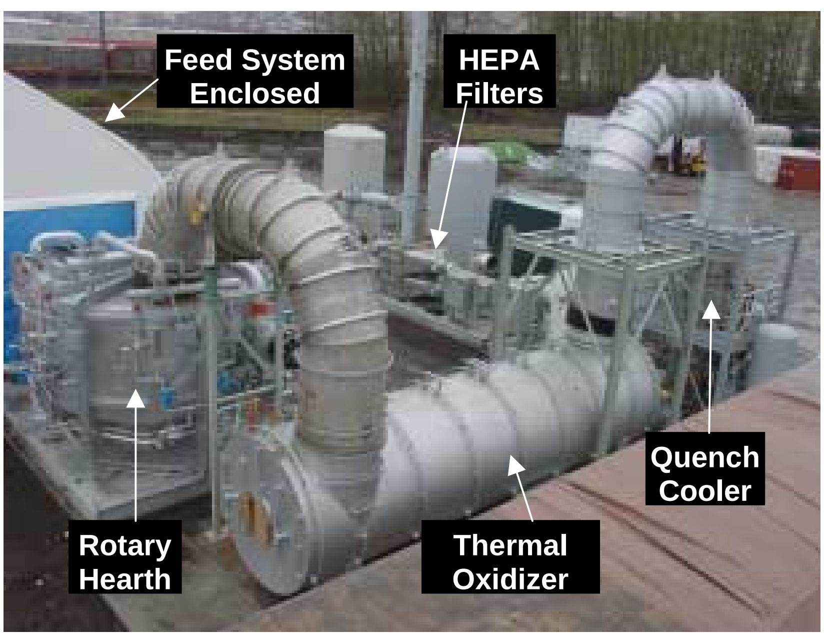

Figure 1. Ten ton/day processing system for asbestos and PCBs

TCCT provides treatment effectiveness equivalent to that of vitrification without the requirement of melting the waste. This makes the technology less expensive and more versatile than vitrification for certain wastes.

Advantages over Baseline

The baseline technology for disposal of asbestos in the United States is land-fill disposal. Thermochemical conversion of ACM has the following advantages over landfill disposal:

- Permanently converts asbestos to non-hazardous, inert material
- Results in significant volume reduction (asbestos is typically low density, taking up valuable landfill space)
- Eliminates potential for future liability issues possible with landfill disposal

If the asbestos is contaminated with PCBs, heavy metals or radionuclides, then the regulatory classification becomes more complex and disposal options become more limited and more expensive. Pretreatment may be required or alternative disposal options such as vitrification may be required. Thermochemical conversion is a cost-effective option for treatment of these types of wastes that are more expensive to dispose (compared to asbestos that does not have other contaminants.)

Potential Markets

Currently the primary market for ARI's TCCT in the US is treatment of ACM that also contains PCB's, metals, and/or radionuclides. Landfill disposal is currently standard practice for disposal of ACM (with out other contaminants). Under the current regulatory and market conditions, TCCT has difficulty competing with landfill disposal for straight ACM, primarily due to cost.

In Europe, where regulatory trends are shifting away from landfill disposal of ACM and requiring "stabilization", destruction or conversion. ARI's technology has a greater market for treatment of straight ACM. ARI is currently in the process of building a system to be sited in Dublin, Ireland.

Demonstration Summary

ARI Technologies, Inc. was contracted by the DOE's National Energy Technology Laboratory (NETL) to demonstrate its thermochemical conversion process. The purpose of the project was to:

- Destroy 10,000 lb. of asbestos-containing material (ACM), defined as asbestos fibers and binder by feeding it through an EPA-permitted asbestos destruction technology, such that the resultant materials are no longer considered to be asbestos in accordance with 40 CFR 61.155; and

- Collect and analyze performance data for the deployed asbestos destruction technology.

- In addition to the mandatory objectives, ARI conducted additional tests on the asbestos designed to evaluate the effectiveness of the technology for immobilization of toxic metals and radionuclides that may be present in DOE asbestos waste.

The demonstration was conducted at ARI's facility in Tacoma Washington, using ACM from the Savannah River Site (SRS). The ACM was transported to Tacoma where it was successfully converted into non-asbestos, non-hazardous aggregate using ARI's technology. The performance and economics of the process were evaluated based on the demonstration.

Based upon the results of the tests conducted under this program and with previous work, ARI has demonstrated that:

- Thermochemical conversion of asbestos can be accomplished effectively and economically;
- The technology is also effective for the destruction of organic wastes (such as PCBs), and can immobilize metals and surrogate radionuclides in the sintered product;

- The system used in this project demonstrated that the residence time required for complete asbestos conversion could be reduced from 50 minutes to 20 minutes at large scale; and
- Additional tests on a smaller scale demonstrated that conversion could be accomplished in 10 minutes.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at www.em.doe.gov/ost under "Publications." The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The Tech ID for ARI Technologies Asbestos Destruction is 3114.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Thermochemical conversion is a patented process that utilizes fluxing agents and heat to promote accelerated solid solution reactions in silicate media. The process involves shredding and then mixing asbestos-containing material (ACM) with proprietary fluxing agents and heating the fluxed mixture. The presence of the fluxing agents at elevated temperatures (approximately 2200°F) results in rapid remineralization of asbestos fibers. The fibers are converted into non-asbestos minerals such as diopside, wollastonite, olivine, and glass.

The ARI process is comparable to vitrification, but does not involve complete melting. Instead, the process results in sintering of the material. This sintering process is robust and very effective on a wide variety of waste types and contaminants. The process is also effective on other types of waste including demolition debris and predominantly organic waste. Pyrolysis of organic compounds takes place in the rotary hearth. The pyrolysis products are directed via an induced draft to a thermal oxidation unit that destroys any residual organic contamination that might be present in the off-gas. From the thermal oxidizer, the off-gases are cooled and scrubbed for particulates and acid components that might be present. The presence of the demineralizing agents accelerates molecular diffusion in inorganic waste during heating. This molecular diffusion results in destruction of inorganic compounds such as asbestos and simultaneous oxidation and molecular bonding of metals and radionuclides within the waste media. This results in immobilization of metals and radionuclides. The process also results in significant volume reduction of the waste. Volume reduction is dependent upon the type of material being treated and can range from 10 percent for soils to over 90 percent for ACM or primarily organic materials.

The sintered product of ARI's process has been evaluated for chemical durability using the PCT. The PCT test is used to assess the leachability of chemicals (including radionuclides) from a vitrified material. The PCT test methods are described by the America Society for Testing and Materials (ASTM) Designation C1285-97. The results of PCT testing on the product of ARI's TCCT, has shown better chemical durability that vitrified products (Timmons, D.M., 2001).

The processing equipment consists of four primary systems including feed preparation, rotary hearth converter, off-gas treatment, and product removal. The system is modular and these systems can be modified independently of the other systems to accommodate a variety of feed materials. Each of the systems is briefly described below.

- The feed system consists of waste handling conveyors, a shredder, mixer, hopper, and a "ram feeder" which compresses the ACM into a brick and simultaneously pushes the compressed ACM onto the rotary hearth.
- The rotary hearth is a flat circular oven that rotates. The rotary hearth used for this project is direct-fired using propane. Waste to be processed is pushed onto the hearth and is then removed after one rotation.
- The off-gas processing system for this project is designed to process PCBs as well as asbestos. Some parts of this system were not used for this project (i.e., secondary thermal oxidizer) because chlorinated organics were not present in the ACM. The portions of the system that were used included a quench cooler, caustic scrubber, demister/reheater and HEPA filtration.
- The treated product is scraped off of the hearth and dropped into a water bath to cool. The product handling system removes the treated product from the water bath using an auger. The auger transfers the treated product into holding bins to await verification testing.

System Operation

ARI's TCCT shown in Figure 1, is a modular system that can be outfitted to suit a specific waste stream. The technology also has the potential to be mobile. For this project, the system was set up at ARI's facility in Tocama and the waste was shipped to this facility for treatment. The system used for this project operates in a batch mode (100lbs per batch) and has a production rate of approximately 800 lbs/hr (10/tons per day), and operates at a temperature of approximately 2200- 2250°F. Operation typically follows the following sequence;

- After being weighed, the bags of ACM are loaded onto the process conveyor that drops them into a shredder where they are reduced to <2-in. diameter particles.
- Once on the conveyor, potential worker exposure is limited. Waste is only handled in an air-locked building maintained at negative pressure and ventilated using HEPA filters. In addition, ductwork draws air out of the waste pre-treatment system and directs it to the HEPA filters to minimize the potential for escape of airborne fibers to the work area.
- The shredded material is dropped into a mixer where 1-gallon of ARI's patented fluxing solution is added and mixed for approximately 2 minutes.
- Once mixing is complete, a gate on the floor of the mixing vessel opens and the mixed ACM is dropped into a Flexwall bucket conveyor that transports the material to the feed hopper.
- From the bottom of the hopper, a ram feeding mechanism compresses the ACM into a brick measuring 18-in. x 3-in. in cross section and pushes approximately 10-lb. of ACM onto the hearth with each stroke.
- The ACM is introduced into the rotary hearth converter.
- After 5-minutes of residence time, the bricks of ACM contacted the rotary "cake breaker". The cake breaker is designed to break up the ACM bricks and distribute the ACM on the hearth to maximize the effective surface area of the ACM and to optimize heat transfer and treatment.
- For this project a residence time of 20-35 minutes in the rotary hearth was utilized at a temperature of 2220-2250°F.
- The converted ACM is easily removed from the hearth with a plow and rake that drops the treated product into a water bath for cooling.
- Samples of the material can be collected from the water bath for analysis. Samples are typically collected on a random basis, at a frequency of one sample per 8 hours of operation to confirm asbestos destruction.
- The treated product is then transferred by auger to holding bins.

SECTION 3
PERFORMANCE

Demonstration Plan

The demonstration of this technology was conducted at ARI's facility in Tocama Washington using 10,000 lbs of ACM transported from SRS. The ACM was generated from the abatement of asbestos at the 284-F Powerhouse facility at SRS, which was completed in February 2000. This ACM was not contaminated with PCBs or radionuclides, but did have a significant amount of lead contamination that was unknown prior to analysis performed during this project.

The demonstration will be discussed in terms of the following activities:

- Initial Characterization of ACM: analysis and characterization of the ACM from SRS
- Residence Time Optimization Tests: involved using a tube furnace to assess the minimum residence time and temperature required to fully convert the asbestos fibers into non-asbestos material
- Full Scale Operations: includes operation of the 10-ton per day system to process the ACM from SRS and evaluate system performance
- Metals Immobilization Testing: involved spiking the ACM with four metals (Cadmium, Lead, Barium, Arsenic) and two surrogate radionclides (Cesium and Cerium) followed by processing in 10 ton per day system.

Analytical Procedures

The following analytical techniques were performed on the waste media indicated:

- Whole rock analysis on treated product using X-ray fluorescence to determine bulk chemistry
- Four acid digestion (hydrochloric, nitric, perchloric & hydrofluoric) followed by ICP & ICPMS to determine the concentration of spiked metals
- Particulate analysis of off-gas using NIOSH 7402 procedures
- Analysis of treated product for asbestos using EPA/600/R-93/116 and SM 2540
- Toxic Characteristic Leach Procedure (TCLP) for Pb, Cd, As and Ba on treated product from spiked samples

Results

Initial Characterization

Upon receiving the ACM from Savannah River, random grab samples were collected of the friable asbestos and of cementaceous asbestos (transite). These samples were submitted to ALS-Chemex Laboratories in Sparks, Nevada for bulk (whole rock) analysis. Five samples of friable asbestos and three samples of transite were analyzed. Figure 1 shows the waste as received from SRS.

Figure 2. Waste ACM received from Savannah River Site.

The results of the preliminary asbestos analysis are provided in Appendix B, Table B-1. The primary differences between the friable asbestos and transite are in the concentrations of SiO_2, CaO, and MgO. Sample 40276-9 appears to consist of a hybrid mix of both types although it was a hard, cemented sample when collected.

Residence Time Optimization Tests

A series of tests were conducted to determine if the residence time in the furnace could be reduced to improve production rates and system economics without sacrificing treatment effectiveness. Previous full-scale asbestos conversion operations required 40 to 60 min. of residence time in the rotary hearth furnace to assure complete conversion of asbestos into non-asbestos minerals. To determine if this residence time could be reduced, a series of tests were performed in a tube furnace, which is a smaller apparatus that is more conducive to optimization testing. These tests involved briquetting of the asbestos followed by heating for different time periods. The information gathered from these tests was used as the basis for reducing the residence time in some of the full-scale test runs.

Samples briquettes that measured approximately 1 7/8" by 7/8" by ½" thick (4.8 by 2.2 by 2.0 cm) were tested. Pairs of briquettes were placed in a nickel combustion boat and heated in a tube furnace at 2200ºF (1204ºC) for 10, 20, 30 and 60 minutes.

Treated samples were examined using electron microscopy at the University of Washington Department of Geological Sciences. The examination included visual inspection of each sample at low and high magnification and collection of Energy Dispersive Spectroscopy (EDS) spectra. The goal of the analysis was to determine the degree to which the asbestos fibers were converted. Figure 3 shows the briquettes after they had been impregnated with epoxy and sections removed for microprobe examination.

Figure 3. Epoxy-impregnated and segmented ACM briquettes (after conversion)

Remnant fibrous structure was observed using the electron microprobe in some of the samples that were heated for 10, 20, and 30 minutes. At high magnification, it was shown that this remnant structure was simply a "ghost" of the fibrous structure that was present in the asbestos prior to processing. The asbestos in all portions of all of the samples were observed to have been converted. No asbestos was identified and no fibers suggestive of the presence of asbestos were identified in any of the samples. In the samples heated for 50 and 60 min., no remnant structure was visible, recrystallization was greatly progressed and remineralization proceeded much further than in the other samples. Figures B-1, 2, and 3 in Appendix B show electron photomicrographs with respectively increasing magnification of the sample that was heated for 10 minutes. The white boxes in Figures B-1 and B-2 show the area that is increased in magnification in the subsequent image. For instance the area shown in Figure B-3, is represented by the white box in the lower magnification image of Figure B-2. In conclusion, the tube furnace tests indicated that a residence time of 10 minutes was sufficient to convert the asbestos present in the ACM from SRS.

Full-Scale Operations

Full-scale testing was conducted in April, 2002 after a lengthy period of delay due to resolving significant engineering and design problems with the newly fabricated system. After the problems with the system were resolved, the ACM from SRS was processed intermittently over a two-day period. Once processing was initiated, it became clear that many of the bags of asbestos contained materials and objects that were not compatible with the material handling system. These objects included a brass valve and regulator, refractory bricks, concrete, sections of pipe, and a piece of lead sheet as shown in Figure 5. These objects repeatedly jammed the shredder, mixer and ram feeder, none of which were designed to accommodate such material. The continued interruption in operations made it necessary for workers to cut open each bag of ACM and inspect the contents prior to feeding the material into the system.

After the difficulties with the foreign objects were resolved, a consistent throughput rate of 800 lb./hr. was attained. Most of the ACM was processed at this production rate with a 35-min. residence time and hearth temperature at 2200ºF. Continuous off-gas monitoring for particulates was conducted during processing.

Based on the data from the tube furnace tests showing that conversion of asbestos could be attained in 10 minutes, a batch of ACM was processed in the converter with a shorter residence time of 20 minutes. For this test, all other aspects of feed preparation, moisture and material handling were the same except that the hearth temperature was set at 2250ºF. A sample of the treated product from this test was also collected and analyzed.

Figure 5. Incompatible debris found in bagged ACM

Results

Four samples of treated asbestos were collected to determine if any asbestos fibers remained in the product following full-scale treatment. These samples were random grab samples collected from the hearth with a stainless steel cup attached to a steel rod and dropped into water to cool immediately upon removal from the hearth. Three samples consisted of treated product that was subjected to processing for a period of 35 min. at a temperature of 2200ºF (1204ºC). The fourth sample collected was from a batch of ACM that was treated with a reduced, 20-minute residence time. No asbestos fibers were found in any of the samples, indicating that all of the asbestos fibers were successfully converted.

Off-Gas Analysis

The off-gas sample was collected continuously during asbestos destruction operations. The sample was collected according to NIOSH 7402 procedures that consist of extracting a gas sample from the system stack and passing it through a filter. Once processing was completed, the filter was prepared and examined using transmission electron microscopy. No asbestos fibers were observed during this examination.

Metals Immobilization

To evaluate the ability of the TCCT to stabilize heavy metal contaminants in ACM, six batches of ACM were spiked with four different metals and two surrogate radionuclides. The metal compounds, their respective spiked quantities and the mass of ACM to which they were added are shown in Table 2. The ACM batches for the metals immobilization tests were mixed in new, clean polyethylene 5-gal. buckets. One bucket for each metal was filled approximately ¾ full of asbestos that had already been processed by the shredder and mixer and to which fluxing solution had been added. The majority of the plastic, paper and other non-asbestos materials were removed from the bucket and the metal compound was added to the bucket. Figure 6 shows metal oxide being added to a bucket of ACM.

The ACM spiked with the metals was mixed thoroughly in the buckets and allowed to sit for 24 hours prior to processing. The quantities of ACM involved with the spiked metal samples were too small to introduce into the system using the ram feeder. In addition, it was necessary to introduce the sample at a discrete location on the hearth and be able to identify the same material on the hearth once it had been processed.

Table 2. Quantities and Concentrations of Metals Added to ACM

Metal	***Chemical Form***	***Mass of Compound Added (g)***	***Mass of Metal Only (g)***	***Kg of Waste***	***Pre-Test Conc. (ppm)***
Barium	BaO	25	22.39	7.25	3089
Arsenic	As_2O_3	10	7.57	8.15	929
Cesium	$CsNO_3$	10	6.82	7.25	940
Cerium	Ce_2O_3	10	8.54	8.15	1047
Cadmium	CdO	10	8.75	8.15	1074
Lead	PbO	10	9.28	6.34	1464

Figure 6. Cesium Nitrate Being Added to ACM

To assure successful introduction and withdrawal of the sample into and out of the rotary hearth converter, a small window was installed in the side of the hearth through which the sample was introduced. Using a stainless steel scoop attached to a long steel handle, the ACM was manually placed on the hearth in a single pile. This pile was placed immediately upstream of the cake breaker. The cake breaker distributed the material on the hearth in the same manner as the asbestos that was introduced by the ram feeder.

The samples were allowed to remain on the rotary hearth for between 31 and 41 min. Once the samples had been processed, a stainless steel cup affixed to the end of a steel rod was used to collect a random grab sample of the treated product. The hot sample was dropped into a steel bucket containing water and allowed to cool. Once the samples were cool, they were placed into 9-oz. glass sample jars. Two sample jars were collected for each spiked metal sample.

Results

There was uncertainty regarding the homogeneity of the samples with respect to the distribution of the spiked metals. Therefore, preparation of these samples for analysis included crushing, mixing and splitting them prior to analysis. Table 3 shows the bulk chemistry and concentrations of the spiked metals for selected samples.

Table 3. Bulk Chemistry and Concentrations of Treated Spiked Metal Samples

	Sample Numbers					
Analyte	***Cd-2200***	***Pb-2200***	***Ba-2200***	***As-2200***	***Cs-2200***	***Ce-2200***
Al_2O_3 wt%	8.58	8.64	8.52	8.30	10.18	9.20
BaO wt%	0.11	0.04	0.36	0.04	0.05	0.04
CaO wt%	21.27	20.52	22.09	21.67	21.17	20.93
Cr_2O_3 wt%	0.10	0.04	0.04	0.04	0.12	0.04
Fe_2O_3 wt%	10.01	11.63	9.26	9.70	10.31	10.21
K_2O wt%	0.89	0.89	0.79	0.77	0.88	0.87
MgO wt%	14.44	12.09	14.47	15.16	14.43	12.82
MnO wt%	0.38	0.36	0.42	0.42	0.42	0.35
Na_2O wt%	1.04	0.93	1.02	0.99	1.01	1.01
P_2O_5 wt%	0.18	0.21	0.17	0.19	0.17	0.20
SiO_2 wt%	41.50	42.73	41.49	41.10	40.37	42.79
SrO wt%	0.08	0.06	0.07	0.07	0.06	0.08
TiO_2 wt%	0.71	0.71	0.67	0.70	0.69	0.71
As (mg/kg)	26.0	26.2	28.2	356	26.8	25.8
Ba (mg/kg)	1363	540	4398	539	480	544
Cd (mg/kg)	218	0.54	2.12	0.80	0.28	0.20
Ce (mg/kg)	67.6	61.0	73.9	62.9	118.0	>500
Cs (mg/kg)	5.40	4.75	4.45	5.15	>500	2.50
Pb (mg/kg)	1840	5330	299	437	4680	1395

Note: Shaded area denotes concentration of spiked metal for each sample.

The data in Table 3 show that the overall composition of the spiked ACM was consistent among the samples. Since these samples intended for the spiked metal tests were collected at random from the feed hopper after several batches of the ACM had been shredded and mixed, these bulk compositions can be considered representative of the overall ACM that was used during all testing. With respect to the concentrations of metals that were used to spike the ACM, the As, Ba, Cd, Ce and Cs exhibited consistently low concentrations for the un-spiked samples and the sample actually spiked with the metal shows significantly higher concentrations of the respective metal. However, for lead, all of the samples showed high lead levels and two of the samples exhibited lead concentrations well above that which could be attributed to spiking (even though only one sample was spiked). It does not appear that volatilization of lead was taking place to any significant extent. Arsenic and cadmium apparently exhibited some volatilization before having a chance to bond in the silicate matrix.

The treated products from the samples spiked with Cd, Pb, Ba, and As were subjected to TCLP testing to determine if thermochemical conversion will immobilize metals to the extent that the treated product will meet land-ban standards. The samples that were spiked with Cs and Ce were not analyzed using TCLP, but were retained for future testing using the Product Consistency Test (PCT). PCT analysis was beyond the scope of this project. However, PCT testing on converted asbestos has been previously performed, the results of which demonstrated superior leach resistance and chemical durability (Holtz, 2001). The importance of such testing is recognized which is why the samples were archived for future analysis.

The results of the TCLP testing were very favorable. In general TCLP results were about 1 order of magnitude better than EPA requirements with the exception of barium. For barium, the results were 2 orders of magnitude better than EPA requirements. Table 4 summarizes the TCLP results.

Table 4. Results of TCLP Analysis for Spiked Samples

Sample Number (metal added)	***Analyte Detected (mg/L)***	***EPA Standard (mg/L)***	***Reporting Limits (mg/L)***
Cd-2200 (Cd)	0.10	1.0	0.01
Pb-2200 (Pb)	0.40	5.0	0.10
Ba-2200 (Ba)	1.26	100.0	0.02
As-2200 (As)	0.30	5.0	0.20

Conclusions

Overall the demonstration of ARI's Thermochemical Conversion Technology was a success. All samples indicated complete conversion of asbestos to non-asbestos material. After the heavy-gauge steel, bricks, and other foreign material had been removed from the feed, ACM was processed at a steady rate of 800 lbs. per hour, which is roughly equivalent to the 10 ton per day rating of the unit. A shorter residence time of 20 minutes was tested with success. Adopting a 20 minutes residence time would increase the daily output to approximately 17 tons per day for the system used. Further decreasing the residence time to 10 minutes (based on successful tests in the tube furnace) could increase production rates to approximately 33 tons per day for the system used.

Testing of ACM spiked with metal surrogates supported ARI's claims that the technology can not only destroy asbestos, but also stabilize heavy metal contaminants to well below TCLP limits. The process also effectively stabilized lead contamination (non-spiked) that was present in the asbestos waste from SRS at elevated levels. Previous PCT testing on converted ACM also demonstrated that the treated product exhibits chemical durability equivalent to or better than that of vitrified radioactive waste of similar composition.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

ARI's thermochemical conversion technology is applicable and cost effective for treatment of asbestos waste that is also contaminated with PCB's, heavy metals, and/or radionuclides. Although the technology is certainly applicable to the destruction of common asbestos waste (that does not have other contaminants), landfill disposal is typically cheaper and is the standard practice in the US. In Europe where regulatory trends are shifting away from land disposal and toward "stabilization" (i.e.destruction/conversion), ARI does see a substantial market for the technology for straight asbestos. The technology is applicable to liquid and solid wastes that are reasonably homogeneous or that can be made so without excessive expense. The technology is modular so that handling systems can be designed to accommodate wastes with various properties.

The technology can be operated at a variety of temperatures adding to its versatility. With the exception of vitrification, it is the only process capable of simultaneously destroying organic contamination and immobilizing metals and radiocuclides. Treatment of asbestos results in a reduction in volume ranging from 50% to 90% depending upon the type of asbestos treated.

The process can treat wastes contaminated with a variety of contaminants including:

- Organic contaminants such as VOCs, SVOCs, PCBs and Dioxin,
- Inorganic contaminants such as asbestos and cyanide,
- RCRA metals including arsenic, lead, chromium, barium, zinc, selenium, cadmium
- Radionuclides that can be vitrified such as transuranic (TRU) elements, cesium, thorium and uranium,
- Mixtures of these contaminants.

Wastes for which there is limited data or for which it is believed that the technology is not economically viable or technically compatible include:

- Mercury
- Gaseous radionuclides such as ^{14}C
- Explosives
- Chemical Agent (Although it is believed that the technology is applicable, there is no data to support such a claim)

Baseline and Competing Technologies

Currently in the US, the standard practice for disposal of asbestos waste is landfill disposal in a permitted facility as regulated by the Toxic Substance Control Act (TSCA). If the asbestos is contaminated with PCBs, heavy metals, or radionuclides, then the regulatory classification can become quite complex and disposal options become more limited and more expensive. Since disposal options for ACM mixed with such contaminants as PCBs, heavy metals, and/or radionuclides depends on several factors, a single baseline method does not exist.

When considering ACM that may also be contaminated with PCBs, RCRA metals, and/or radionucles, each of these additional contaminants has an additional set of regulations that must be considered. PCBs, like asbestos are regulated under TSCA, RCRA metals above "characteristic" levels will trigger a RCRA designation and Land Disposal Restrictions (LDR) may apply. Disposal of ACM contaminated with radioactive constituents will add further regulation under the Atomic Energy Act. ACM that is co-contaminated with these constituents, in some cases may be legally disposed in a permitted landfill, but depending on the concentration of the co-contaminants, pretreatment may be required. Some concentrations of PCBs, may require incineration in a TSCA incinerator or an EPA approved alternative. ARI's process is an EPA-approved alternative.

In Europe, where regulatory trends are shifting away from landfill disposal of ACM, technologies like ARI's TCCT may play a larger role in disposal of ACM. On July 19, 1996, Circulaire No. 96-60 was adopted as European Commission (E.C.) Directive. This directive stipulates that all friable asbestos should be "stabilized" prior to disposal by January 2002. Following this, each European country then has to adopt the legislation into law and enact it with a specific effective date.

With respect to asbestos legislation in Europe, Belgium, Luxemburg, Germany, Austria and Denmark have established legislation requiring stabilization of asbestos. Netherlands, France and Italy passed legislation banning landfilling at a future date. Netherlands legislation states that landfilling will be banned "as soon a alternative technology exists with a target date of 2002 at the latest". France originally said by 2000, then changed it to 2002, then again to "when reasonably practicable". Italy passed legislation but has not yet set a date for enactment. The U.K. has done nothing and continues to landfill everything including liquid waste. Ireland continues to export ACM, but a contract has been signed with a private company to establish an ARI thermochemical treatment system near Dublin.

Competing Technologies

Competing technologies that have attained commercial status for destruction of asbestos are few. In Europe, there are several technologies that have attained varying levels of development. A summary of these technologies is included in Table 5 below. Note some web site references are not available in English.

Table 5. Summary of Competing Conversion Technologies.

Technology Name/Company	Description	Maturity	Comments
Inertam	Plasma arc system developed by a subsidiary of Electricite De France (EDF)	Commercially available	Their unit costs are \$800 to \$1,200/ton. http://www.inertam.com/
Natron	Process involves heating asbestos in the presence of sodium hydroxide	Lab Scale	http://www.pz.nl/aoo/pdf/mer/achtergrond/A04(asbest).pdf
PEC, Gibros PEC	Thermal process at 1450°F that is essentially vitrification	Pilot Scale	http://www.afval.noordhoek.nl/archief/2001/sita_start_pilot_asbestrecycling.htm
Asbestex	Thermal process to remove water and then shred the waste "so all fibers disappear completely". The end product is a calcium-rich powder	Pilot Scale	European unit cost estimates range from \$136-530/ton depending on scale
Aspireco	Thermal process that heats asbestos to 650ºC to remove water	Pilot scale	
Cordiam	Asbestos is mixed with kaolinite clay (40% asbestos to 60% clay), heat to 650 - 950ºC to make tiles and bricks http://www.area.fi.cnr.it/r&f/n8/abruzzese.htm	Pilot scale	Pilot project sponsored by Italy's National Research Council (CNR). Preliminary unit cost estimates at \$190/ton.
Ultramac, Offered by Assing Co.	Asbestos is crushed then heated to 650-700ºC. The end product (dust) can reportedly be used in cement manufacture.	Lab Scale	

Patents/Commercialization/Sponsor

Thermochemical conversion is a patented technology (U.S. Patent# 5,096,692) and is protected in the United States, Canada and 14 industrialized European nations. The technology has been successfully commercialized. ARI is in the process of designing a new system that will be built in the United States and shipped to Ireland where it will become a stationary processing facility with the capability to process most (if not all) of that country's waste asbestos.

SECTION 5
COST

Methodology

The purpose of this section is to present the cost of ARI's process and to compare it to the baseline of landfill disposal and other alternative treatment methods. The disposal costs for ACM waste that is also contaminated with PCBs, RCRA metals, and or radionuclides are provide in general terms, since these costs are highly variable depending on waste classification, contaminant-concentrations, and particular disposal method. The cost analysis is meant to provide a general benchmarking of ARI's process compared to other disposal options.

The costs for ARI's TCCT presented here were provided by ARI and are based on a 37 ton per day unit that is currently in development for commercialization in Europe. Data gathered from this demonstration project was incorporated into the cost estimates provided.

Cost Analysis

ARI's Thermochemical Conversion Technology (TCCT)

The cost estimates presented here for ARI's TCCT are based on the following assumptions:

- System Description: 37 ton/day system, direct fired with heat recovery, with dry lime scrubber
- Capital Cost: incorporated based on 7 year capital recover period at a real discount rate of 3.0 percent (OMB, 2002)
- Operating Conditions: 24 hr/day operation, 80 percent operating efficiency, 9 person crew
- Cost include fuel (kerosene), electricity, process chemicals, personal protective equipment (PPE), regular maintenance, and HEPA filters
- Overhead and profit are also included
- Disposal of treated materials is not included
- Transportation to the treatment facility is not included

The capital cost for the 37 ton per day unit is approximately $3 million dollars. Using the assumptions presented above, a 37 ton/day system can treat ACM for approximately $175 - $225 per ton.

The three largest most significant contributors to the overall cost are fuel, capital equipment, and labor. Fuel makes up approximately 36 percent of the total cost, capital equipment makes up 30 percent, and labor comprises about 22 percent of the total cost. Other items such as reagent, maintenance, water, electricity, PPE, and HEPA make up the remaining 12 percent of the overall cost.

Transportation costs are not included, but may play a significant role in cost effectiveness for a specific site. Waste ACM will likely be transported to fixed facility for treatment. Disposal of the treated product may also contribute to the overall cost if a re-use for this material can not be identified. The volume of the treated product will be significantly reduced from the original waste (up to 90%), but may require landfill disposal depending on contaminants present.

Landfill Disposal

The baseline technology for disposal of asbestos in the United States is landfill disposal. The costs for landfill disposal in the U.S. ranges from about $40/yard to about $80/yard. Depending upon the type of asbestos being disposed, the cost per ton can vary. Asbestos abated from SRS is typicall taken to a certified landfill specifically for asbestos with a disposal fee of approximately $58 /ton. Under the current regulatory and market conditions in the U.S., ARI's process is not cost competitive with landfill disposal of common asbestos that does not have additional co-contaminants.

When considering ACM that may also be contaminated with PCBs, RCRA metals, and/or radionuclides, disposal regulations become more complex and disposal options more costly. For example the cost for landfill disposal of DOE waste at Oak Ridge's newly constructed on site Environmental Waste Management Facility is approximately $165 per cubic yard according to a DOE News Release (DOE, 2002). This facility is designed and permitted to accept low-level radioactive, mixed hazardous waste and PCBs. Since asbestos typically has a density of approximately 0.5 tons per cubic yards, the equivalent cost would be $330 per ton. This cost does not include transportation or pretreatment that may be required to meet Waste Acceptance Criteria. For a given site, transportation and pretreatment could add significant cost depending on the location of the site generating the waste and the contaminants present in the waste. ARI's costs for thermochemical conversion are significantly lower than this cost ($330 per ton) and ARIs process results in permanent destruction of asbestos, which is ultimately preferable.

Vitrification

Waste vitrification can be accomplished by a number of different technologies that vary in cost. In general, the cost for waste vitirification is typically greater than $500 per ton, but can be as high as $2,000 per ton. ARI's technology produces a solidified product, similar in chemical durability to a vitrified material, but at a much lower cost.

Cost Conclusions

The cost for thermochemical conversion of ACM using ARI's technology ranges form approximately $175 to $225 per ton based on the conditions described. The cost of conversion by ARI's process is not currently competitive with landfill disposal of ACM in the US, which typically costs between $50-100 per ton (for ACM waste with out other co-contaminants). ARI's process is cost effective for, and uniquely suited to treatment of ACM that may also be contaminated with PCBs, RCRA metals, and/or radionuclides. Although this waste may be disposed of in a landfill under some conditions, the cost is greater and pre-treatment may be required. From the standpoint of performance, ARI's conversion process is comparable to vitrification, but as discussed above, ARI's process costs much less.

SECTION 6
OCCUPATIONAL SAFETY AND HEALTH

Required Safety and Health Measures

The predominant risk associated with handling asbestos-containing material (ACM) is respiratory exposure from breathing asbestos fibers that may be suspended in the air. There are other risks associated with the treatment equipment that are not uncommon to industrial machines and equipment. Physical hazards include slips, trips and falls, potential for cuts or punctures from sharp objects associated with the waste and potential for back injuries from lifting waste during loading operations.

Risk of asbestos exposure with thermochemical conversion is minimal when appropriate procedures and practices are followed. Waste asbestos is delivered sealed in double plastic bags, is typically wet (which minimizes potential for airborne particulates) and the bags are simply loaded onto a conveyor. Once on the conveyor, there is limited potential for exposure to workers. Nonetheless, significant measures are taken to protect workers and the environment. Waste is only handled in an air-locked building maintained at negative pressure and ventilated using HEPA filters. The atmosphere inside of the materials-handling building is monitored continuously. In addition, ductwork draws air out of the waste pre-treatment system and directs it to the HEPA filters to minimize the potential for escape of airborne fibers to the work area.

Workers use Level "C" personal protection equipment (PPE). This consists of respiratory protection and measures to prevent workers from transporting contaminated clothing and personal effects away from the work area. Respiratory protection consists of positive pressure full-face respirators with filtered air. Disposable coveralls, boot covers, gloves and hoods are worn to minimize contact with asbestos fibers. The disposable personnel protection equipment is processed in the conversion system for disposal.

Operation of ARI's TCCT, at their facility in Tacoma, is governed by a comprehensive safety plan that covers all potential process hazards. Operators and workers receive training in safe operation of the process equipment. Heavy gloves are worn to protect workers hands from cuts and bags are typically limited to 50 lb. or less thus minimizing the potential for back injuries. The work area is kept clean and uncluttered to prevent slips, trips and falls. At the end of a work shift, each worker removes PPE following a prescribed decontamination procedure and showers before leaving the decontamination trailer. This prevents transport of contamination off site.

Safety and Health Lessons Learned from Demonstrations

As noted in the Performance section, due to the presence of large objects that disrupted the shredding process, bags of asbestos were opened and visually inspected. This is undesirable from a health and safety standpoint. ARI plans to incorporate both management practices and engineering controls to avoid manual inspection. This issue is also addressed in Lessons Learned Section. The demonstration proceeded smoothly. No injuries occurred and no safety issues were discovered that would warrant correction.

Comparison with Baseline and Alternative Technologies

Comparing ARI's process to landfill disposal from the standpoint of worker health and safety is somewhat subjective. When executed properly, neither the process of placing bagged ACM in a landfill, nor ARI's conversion process should generate air-born asbestos fibers. One might argue that ARI's process, by nature has more risk because it is more active, and requires more energy input (for waste shredding and heating), compared to landfill disposal. Although this is true, ARI's process is very controlled and has many integrated safety measures. Landfill disposal, if not done properly, can result in bags of ACM waste being punctured during placement, which may ultimately generate an airborne hazard. This comparison is strictly from a worker perspective and does not consider future potential human or environmental exposure. This will be addressed in the following section under "Environmental Issues".

Comparing ARI's TCCT to such alternatives as vitrification is also difficult considering variations in vitrification technologies and the limited amount of information regarding technologies actually demonstrated for vitrification of asbestos. Waste vitrification can be accomplished in a variety of ways, such as joule-heated melters, direct-flame melters, plasma-arc melters, and electromagnetic heating. As a class of technologies, it is difficult to compare the occupational safety and health issues of vitrification to those associated with TCCT, but both are high-temperature processes that have risks inherent to these high temperatures. Vitrification typically involves a molten material, which requires unique handling precautions and some vitrification technologies are electrically driven by high voltage power, creating potential electrical hazards.

SECTION 7
REGULATORY AND POLICY ISSUES

Regulatory Considerations

Through various projects, ARI has demonstrated the ability to obtain the required operation permits on a local, state, and federal level for destruction of asbestos and PCBs, two highly regulated wastes. Treatment and disposal of asbestos is regulated by 40 CFR Part 61 Subpart M. In order to obtain a permit for treatment/destruction of asbestos on a production basis, an initial performance test is required during which the process is closely monitored. ARI completed this performance test in 1999 and is now permitted to construct and operate multiple operation systems.

Permitting requirements for operation of the system in Tacoma, Washington were uncomplicated, but required approvals from several agencies. A permit was required from the Puget Sound Air Quality Agency for air emissions and off-gas monitoring was required. The state of Washington Department of Ecology requested that ARI advise them of activities, but they do not oversee TSCA-regulated activities and did not become directly involved. The City of Tacoma Water and Sewer District regulates sewer discharge. However, ARI was able to evaporate all of its water discharge and did not need to obtain a permit for sewer discharge. The Tacoma/Pierce County Solid Waste Division (TPCSW) was interested in the fate of the treated product, which is regulated as a solid waste. Although the product can be recycled as aggregate, the small quantity made it difficult to find an organization interested in the material. Lacking a source for recycling of the product, TPCSW agreed to certify that the product was non-hazardous and requested that ARI dispose of the product at a solid waste landfill.

ARI Technologies, Inc. has received a national permit from the US Environmental Protection Agency (EPA) for the destruction of PCB's in its mobile thermochemical conversion technology. Processing of ACM containing radionuclides and/or RCRA constituents would require additional permitting.

Risks, Benefits, Environmental and Community Issues

Destruction of asbestos by ARI's process eliminates the long-term environmental risk associated with landfill disposal of asbestos. Thermochemical conversion of asbestos permanently converts asbestos to non-hazardous inert minerals, reduces the volume of the waste significantly, and produces a potentially useful product. In contrast, land disposal does not destroy asbestos fibers nor does it eliminate liability associated with the waste.

Regarding the destruction of PCBs, the process has demonstrated greater than >99.9999% destruction efficiency. The gases produced in the hearth are directed via induced draft to a secondary thermal oxidation unit that destroys any residual organic contamination that might be present in the off-gas. From the thermal oxidizer, the off-gases are cooled and scrubbed for particulates and acid components that might be present.

ARI has not encountered objections from the community regarding the operations that it has conducted anywhere despite several public notices for intent to process waste. The process is not considered to be incineration by the EPA, thus avoiding many of the public objections associated with incinerators or technologies perceived to be incineration.

SECTION 8
LESSONS LEARNED

Implementation Considerations

Only one difficulty was encountered during processing of the DOE asbestos. This was the incompatibility of the ARI material handling system with some of the foreign objects that were discovered in the waste. Despite assurances in the Site Agreement from Savanna River that the asbestos would not contain such foreign material, it was present to the extent that it interrupted operations several times. The interruptions were significant enough for ARI to require that each bag be opened and inspected prior to processing.

ARI has evaluated this situation and intends to implement a three-fold approach to prevent the difficulties encountered from occurring during future operations. These include:

- Make specific requests and/or require that the abatement contractor segregate foreign objects during the abatement process. This should not be difficult since the material is all manually handled anyway,
- Specify more robust shredding equipment for material handling system that has the ability to shred such foreign material,
- Scan bags of waste on the feed conveyor with a magnetic sensor so that they can be removed prior to introduction into the feed system.

ARI believes that these three precautionary steps would essentially eliminate process shutdowns associated with introduction of foreign objects.

Technology Limitations and Needs for Future Development

The results of the tube furnace tests indicated that asbestos can be converted into non-hazardous materials in less than 10 minutes. In addition, residence times for large-scale processing was reduced to 20 minutes and no residual asbestos was detected in the treated product. Additional work may further reduce the residence time required to achieve complete conversion. Even small reductions in residence time will equate to significant increases in throughput capacity and improved economics.

Technology Selection Considerations

Thermochemical conversion is a good candidate for waste treatment under a variety of circumstances including:

- Increased public opposition to landfilling of asbestos wastes; and
- Asbestos waste contaminated with other wastes including organics, metals, and certain radionuclides where treatment is preferred or required.

Each site and each waste is different. Typically the unique characters of each situation require some level of testing and evaluation.

APPENDIX A
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APPENDIX B
Table and Figures

Subsection Title

Table 1. DOE Asbestos Sample Analysis

	Friable Asbestos					***Transite***		
Sample	***40276-1***	***40276-2***	***40276-5***	***40276-6***	***40276-10***	***40276-7***	***40276-8***	***40276-9***
SiO2	12.04	12.21	15.46	16.10	14.88	59.52	60.01	20.87
TiO2	0.02	0.02	0.06	0.06	0.06	0.22	0.23	0.09
Al2O3	0.23	0.16	1.43	1.57	1.39	1.08	1.10	2.60
Fe2O3	5.53	5.43	7.71	8.17	7.34	0.55	0.74	11.85
FeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.04	0.04	0.16	0.18	0.16	0.01	0.01	0.20
MgO	78.49	78.68	70.55	69.00	71.17	2.12	1.22	56.13
CaO	2.98	2.86	3.82	3.89	3.82	36.01	36.20	7.53
Na2O	0.48	0.41	0.44	0.59	0.73	0.04	0.01	0.14
K2O	0.02	0.02	0.22	0.24	0.26	0.42	0.43	0.39
P2O5	0.17	0.16	0.16	0.22	0.20	0.02	0.04	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LOI	51.53	51.44	49.31	48.47	49.27	17.96	19.59	44.35

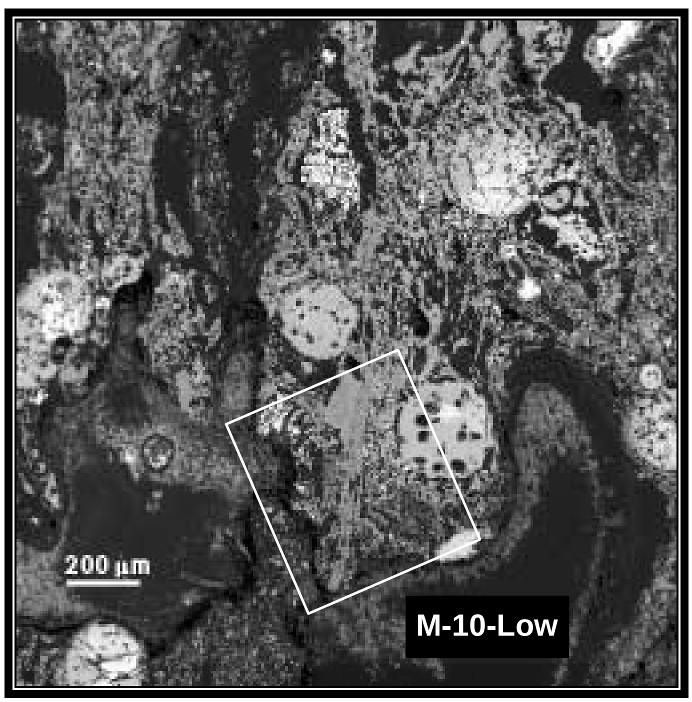

Figure B-1. Low magnification image of ACM billet heated for 10 minutes. Remnant fibrous structure can be seen in the white box.

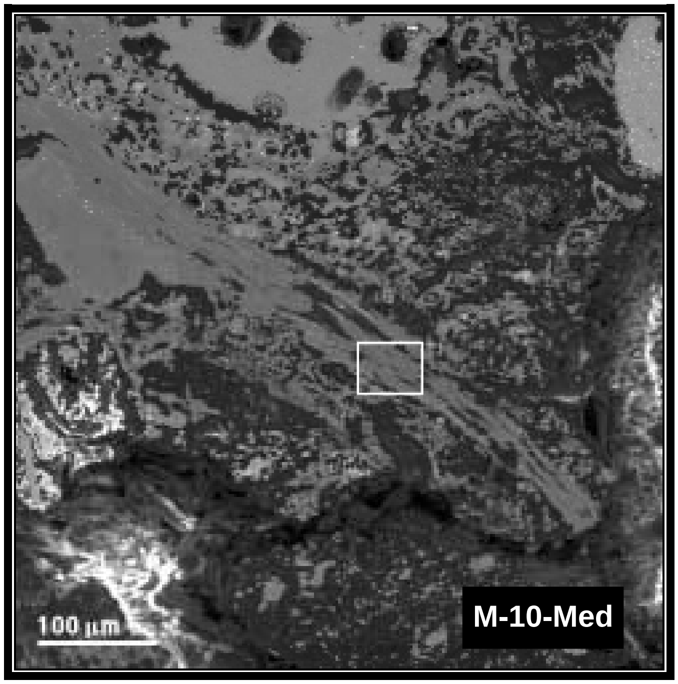

Figure B-2. Medium magnification of mineral fragment observed to have remnant fibrous structure. It is believed that this fragment (extending from upper left to lower right) was friable asbestos prior to treatment.

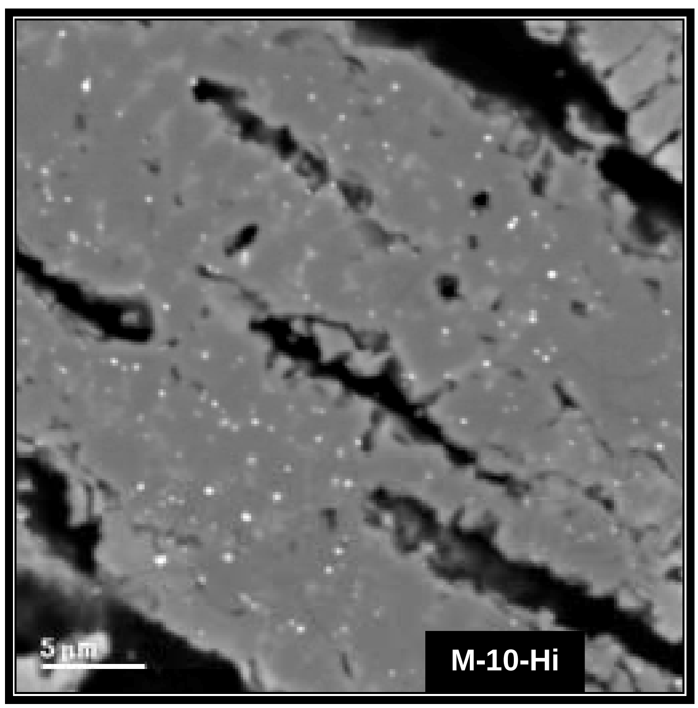

Figure B-3. High magnification image of area depicted in white box in Figure 4B. No indication of asbestos fibers is present. Remineralization of asbestos has formed glass (light-shaded areas), forsterite (dark-shaded areas) and magnetite (small white specks)

APPENDIX D
ACRONYMS AND ABBREVIATIONS

ACM	Asbestos Containing Material
AEA	Atomic Energy Act
CFR	Code of Federal Regulations
DOE	Department of Energy
EDS	Energy Dispersive Spectroscopy
EPA	Environmental Protection Agency
LDR	Land Disposal Restrictions
NETL	National Energy Technology Laboratory
NIOSH	National Institute of Occupational Safety and Health
HEPA	High Efficiency Particulate Air
OST	Office of Science and Technology
PCB	Polychlorinated Biphenyls
PCT	Product Consistency Test
RCRA	Resource Conservation Recovery Act
SRS	Savannah River Site
SVOC	Semi-volatile Organic Compounds
TRU	Transuranic
TCCT	Thermochemical Conversion Technology
TCLP	Toxicity Characteristic Leaching Procedure
TPCSW	Tocama/Pierce County Solid Waste
TSCA	Toxic Substance Control Act
VOC	Volatile Organic Compounds