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THERMOCHEMICAL CONVERSION OF ASBESTOS CONTAMINATED WITH RADIONUCLIDES AND/OR OTHER HAZARDOUS MATERIALS

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ABSTRACT

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, metals regulated under the Resource Conservation Recovery Act (RCRA) and perhaps other regulated components that may require treatment instead of landfill disposal. Land disposal 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 for the destruction of asbestos-containing wastes is thermochemical conversion technology.

ARI Technologies, Inc. was contracted by the National Energy Technology Laboratory (NETL) to conduct a technology deployment of its thermochemical conversion process. The purpose of the project was to:

1. "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, Standard for Operation that Convert Asbestos-Containing Waste Materials Into Non-asbestos and,
2. Collect and analyse performance data for the deployed asbestos destruction technology."

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

This full-scale technology deployment demonstrated economical asbestos destruction and effective immobilization of lead, cadmium, barium and arsenic. Cerium oxide and non-radioactive cesium were also immobilized. Leach testing using EPA and DOE methods showed that leach performance surpassed regulatory criteria by at least one order of magnitude.

1.0 INTRODUCTION

1.1 PROCESS DESCRIPTION

Thermochemical conversion is a patented process that utilizes fluxing agents and heat to promote accelerated solid solution reactions in silicate media. Briefly, 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 results in remineralization of asbestos fibers. The fibers are converted into non-asbestos minerals such as diopside, olivine and glass.

The processing equipment used 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 introduces 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 experiencing one rotation.

- The off-gas processing system on the unit that was used 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 they are not required for treatment of asbestos. 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.

Figure 1 shows a photograph of the system that was used for this project.

Figure 1. Thermochemical Conversion System

NOMENCLATURE

ACM	Asbestos Containing Material
ASTM	American Society for Testing and Materials
DOE	Department of Energy
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Accumulation
LOI	Loss on Ignition
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety & Health
PCT	Product Consistency Test
RCRA	Resource Conservation Recovery Act
TCCT	Thermochemical Conversion Technology
TCLP	Toxic Characteristic Leaching Procedure
TEM	Transmission Electron Microscopy
TSCA	Toxic Substances Control Act

1.2 PROJECT DESCRIPTION

The tasks to be performed under this contract included the execution of a site agreement, mobilization, operations, demobilization, deliverables, and briefings.

1.3 SITE AGREEMENT

One of the requirements of the contract was to establish a partnership within the DOE complex. To establish the partnership, ARI and the DOE site needed to execute a Site Agreement. This Site Agreement included:

- A description of the DOE site's baseline asbestos abatement program and associated costs including disposal,
- A detailed description of the ACM to be processed,
- Authorization to receive and process ACM,
- A discussion of the DOE NEPA document,
- Roles and responsibilities of the key entities,
- DOE site infrastructure requirements and authorities,
- Regulatory requirements and permits,
- Duration of activities—i.e., period of performance,
- Final disposition of treated product.

An asbestos abatement project at the DOE's Savannah River Facility was identified, the timing of which was commensurate with the goals and objectives of this project. A Site Agreement was executed with Westinghouse Savannah River Company that met all of the DOE requirements.

1.4 MOBILIZATION

Mobilization tasks included transporting the ACM to Tacoma, Washington and storage of the ACM pending processing. The load of asbestos consisted of 441 bags of ACM weighing approximately 10,000 lb. The ACM was double-bagged with heavy-gauge polyethylene and taped. The bags were typically intact although sharp objects they contained had pierced some. Many of the bags contained free water presumably from the abatement activities.

The transport of the ACM conformed to all applicable federal, state and local laws and regulations and, once on site, the waste was stored in a locked shipping container and appropriately labeled. Approval was received from the Puget Sound Clean Air Agency (PSCAA) to conduct the test. PSCAA was the lead regulating authority for this project.

1.5 PRE-TEST ANALYTICAL WORK

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 analysed. Table I shows the results of the analyses.

The data in Table I show that the primary differences between the friable asbestos and transite are in the concentrations of SiO2, CaO and MgO. Sample 9 appears to consist of a hybrid mix of both types although it was a hard, cemented sample when collected.

Table I. Normalized DOE Asbestos Sample Analysis

	Friable Asbestos					***Transite***		
Sample	***1***	***2***	***5***	***6***	***10***	***7***	***8***	***9***
SiO_2	12.04	12.21	15.46	16.10	14.88	59.52	60.01	20.87
TiO_2	0.02	0.02	0.06	0.06	0.06	0.22	0.23	0.09
Al_2O_3	0.23	0.16	1.43	1.57	1.39	1.08	1.10	2.60
Fe_2O_3	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
Na_2O	0.48	0.41	0.44	0.59	0.73	0.04	0.01	0.14
K_2O	0.02	0.02	0.22	0.24	0.26	0.42	0.43	0.39
P_2O_5	0.17	0.16	0.16	0.22	0.20	0.02	0.04	0.20
Total	100	100	100	100	100	100	100	100
LOI	51.53	51.44	49.31	48.47	49.27	17.96	19.59	44.35

1.6 TUBE FURNACE TESTS

Previous full-scale asbestos conversion operations required 40 to 60 min. of residence time in order to assure complete conversion of asbestos into non-asbestos minerals. To determine if this residence time could be reduced (which would result in higher production rates and better economics), a series of tests were performed involving briquetting of the asbestos followed by heating for different time periods in a tube furnace. The information gathered from these tests was used to further test the material at full scale.

Samples were prepared using a Komarek laboratory briquetter to produce briquettes that measured approximately 1 7/8” by 7/8” by ½” thick (4.8 by 2.2 by 2.0 cm). 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. Following heating, the briquettes were removed from the furnace and allowed to cool at room temperature.

The samples were examined with a Joel 733 Superprobe 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 EDS spectra. The EDS spectra were used in an effort to identify the elemental makeup of suspicious-looking fragments or fibrous material and see if the elemental makeup was similar to that of asbestos or serpentine. Wavelength dispersive spectroscopy (WDS) was also performed on specific minerals to aid in their identification.

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.

No asbestos was identified and no fibers suggestive of the presence of asbestos were identified in any of the samples. All portions of all of the samples were observed to have been converted. In the samples heated for 50 and 60 min., no remnant structure was visible and remineralization proceeded much further than in the other samples. Figures 2A, 2B and 2C show electron photomicrographs with respectively increasing magnification of the sample that was heated for 10 minutes. The white boxes in Figs. 2A and 2B show the area depicted in the following image.

1.7 FULL-SCALE OPERATIONS

The test schedule was established for the ACM to be processed during the week of April 1, 2002. Warm-up of the rotary hearth converter commenced at 8:00 A.M. on April 1 and continued for the remainder of the day and through the night of April 1. A nominal process temperature of 2200ºF (1204ºC) was attained at approximately 10:00 AM on April 2.

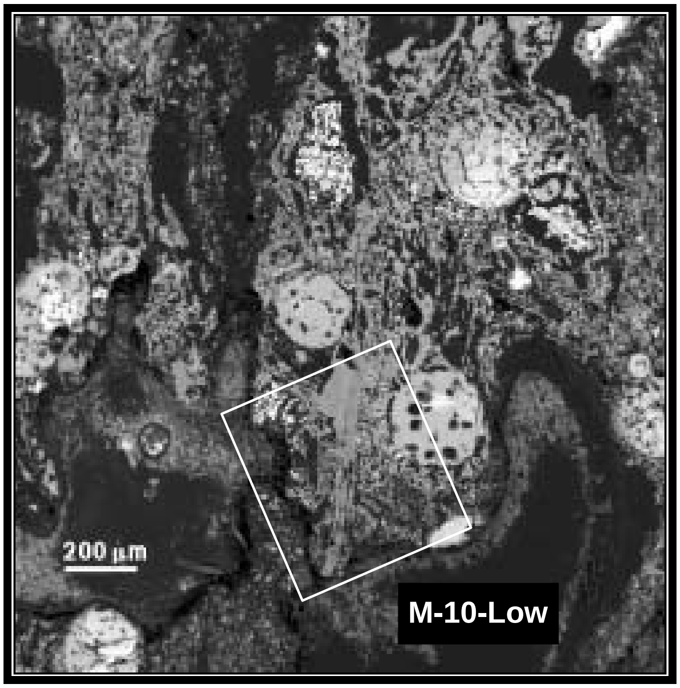


Figure 2A. Low magnification image of ACM billet heated for 10 minutes. Remnant fibrous structure can be seen in the white box.

The ACM was subjected to pre-treatment in batches of approximately 100-lb./batch. After weighing, the bags of ACM were conveyed and dropped into a shredder where they were shredded to consistently sized particles. The shredder dropped the batch of shredded material into a mixer where ARI’s patented fluxing solution was added while mixing continued for approximately 2 minutes. Once mixing was completed, a gate on the floor of the mixing vessel was opened and the mixed ACM was dropped into a conveyor that transported the material to the feed hopper. From the bottom of the hopper, the ram feeding mechanism introduced the material onto the hearth for processing.

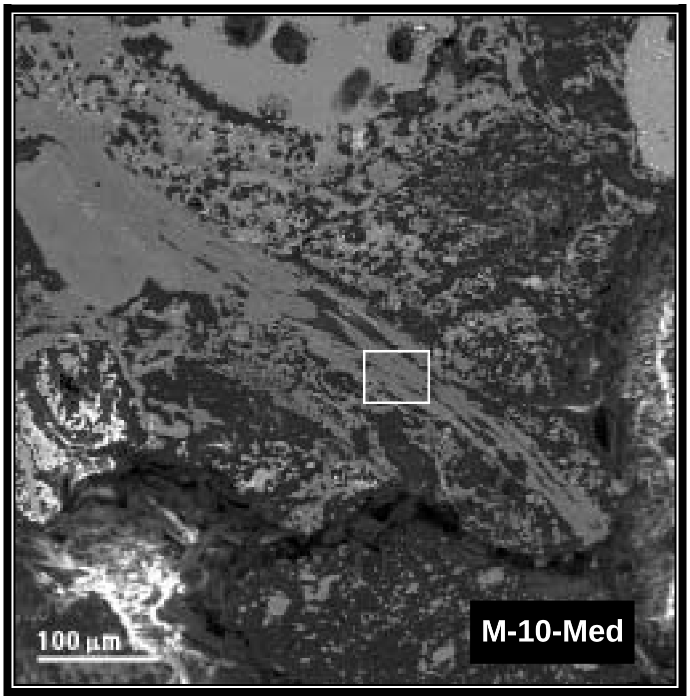


Figure 2B. Medium magnification of mineral fragment observed to have remnant fibrous structure. It is believed that this fragment (extending from upper left to lower right) was friable asbestos prior to treatment.

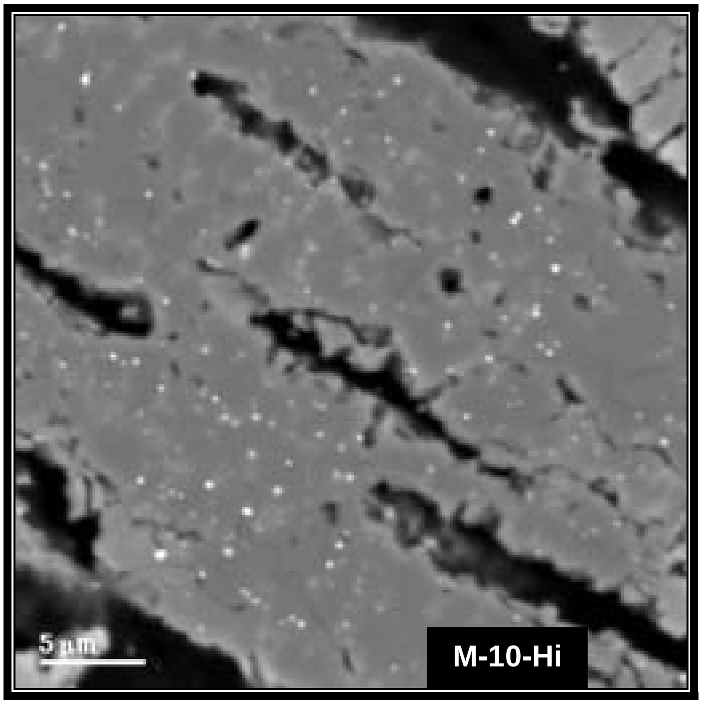


Figure 2C. High magnification image of area depicted in white box in Fig. 2B. No indication of asbestos fibers is present. Remineralization of asbestos has formed glass (light-shaded areas), forsterite (dark-shaded areas) and magnetite (small white specks).

The rotary hearth converter was operated at a temperature of 2200ºF with a residence time of 35-min. for the ACM. Once the ACM was introduced into the rotary hearth converter, it began its rotation. The converted ACM was easily removed from the hearth with a Hastalloy plow and rake that dropped the treated product into a water bath for cooling. It is at this location that samples were collected. The treated product was then transferred by auger to holding bins.

The system was operated for two days during which the ACM was processed intermittently. 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.

1.8 EVALUATION OF PRODUCTION RATES

Because the data from the tube furnace tests showed that conversion of asbestos could be attained in 10 minutes, additional ACM was processed in the converter with a residence time of 20 minutes to see if residence time could be minimized. For these additional tests, all other aspects of feed preparation, moisture and material handling was the same except that the hearth temperature was set at 2250ºF. Samples of treated product from these tests were also collected and analysed. Near the end of the processing phase, some additional tests were conducted to evaluate the effectiveness of the process for immobilization of metals and surrogate radionuclides.

1.9 EVALUATION OF METALS IMMOBILIZATION

Six batches of ACM were prepared, each containing a separate metal compound. The metal compounds, their respective spiked quantities and the mass of ACM to which they were added are shown in Table II.

Table II. Metals Added to ACM

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

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.

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.

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.

The samples were allowed to remain on the rotary hearth for 31 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 sample jars. Two sample jars were collected for each spiked metal sample.

2.0 ANALYTICAL PROCEDURES AND RESULTS

The following analytical techniques were performed on the untreated waste and/or treated product:

- 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 methods 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,
- Product Consistency Testing (PCT) on selected samples of treated product.

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 III shows the bulk chemistry and concentrations of spiked metals for selected samples.

The data in Table III show that the major oxide compositions of the treated product produced from the spiked metal tests were consistent among the samples. These samples were collected at random and at different times from the feed hopper after several batches of the ACM had been shredded and mixed. Thus, their similarity indicates that the compositions in Table III are representative of the overall ACM that was used during all testing.

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

Analyte	***Sample Number***					
wt%	***CD-1***	***Pb-1***	***Ba-1***	***As-1***	***Cs-1***	***Ce-1***
Al2O3	8.58	8.64	8.52	8.30	10.18	9.20
BaO	0.11	0.04	0.36	0.04	0.05	0.04
CaO	21.27	20.52	22.09	21.67	21.17	20.93
Cr2O3	0.10	0.04	0.04	0.04	0.12	0.04
Fe2O3	10.01	11.63	9.26	9.70	10.31	10.21
K2O	0.89	0.89	0.79	0.77	0.88	0.87
MgO	14.44	12.09	14.47	15.16	14.43	12.82
MnO	0.38	0.36	0.42	0.42	0.42	0.35
Na2O	1.04	0.93	1.02	0.99	1.01	1.01
P2O5	0.18	0.21	0.17	0.19	0.17	0.20
SiO2	41.50	42.73	41.49	41.10	40.37	42.79
SrO	0.08	0.06	0.07	0.07	0.06	0.08
TiO2	0.71	0.71	0.67	0.70	0.69	0.71
mg/kg	--	--	--	--	--	--
As	26.0	26.2	28.2	356	26.8	25.8
Ba	1363	540	4398	539	480	544
Cd	218	0.54	2.12	0.80	0.28	0.20
Ce	67.6	61.0	73.9	62.9	118.0	>500
Cs	5.40	4.75	4.45	5.15	>500	2.50
Pb	1840	5330	299	437	4680	1395

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 significantly higher concentrations of the respective metal in the spiked sample (as expected). However, 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). Clearly there was lead contamination on the asbestos waste provided by the DOE. 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 off-gas sample was collected continuously during asbestos destruction operations. As mentioned above, 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 (TEM). No asbestos fibers were observed during this examination.

Four samples of treated asbestos were collected to determine if any asbestos fibers remained in the product following treatment. These samples were collected in the same manner as those for the spiked metal samples. They were random grab samples collected from the hearth with a stainless steel cup attached to a steel rod and dropped into water to cool. Three of the four samples consisted of treated product from the bulk of the material processed that was subjected to processing for a period of 35 min. at a temperature of 2200ºF (1204ºC). Near the end of the test, the rotational velocity and temperature of the hearth was increased and a batch of ACM was processed for 20 minutes at a temperature of 2250ºF (1232ºC). No asbestos fibers were found in any of the samples using TEM.

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 results of the TCLP testing were very favorable. In general TCLP results were about one order of magnitude better than EPA requirements with the exception of barium. For barium, the results were two orders of magnitude better than EPA requirements. Table IV summarizes the TCLP results.

Table IV. Results of TCLP Analysis for Spiked Samples

Sample Number (metal added)	*Analyte Detected (mg/L)*	*EPA Standard (mg/L)*	*Reporting Limits (mg/L)*
Cd-1 (Cd)	0.10	1.0	0.01
Pb-1 (Pb)	0.40	5.0	0.10
Ba-1 (Ba)	1.26	100.0	0.02
As-1 (As)	0.30	5.0	0.20

2.1 PRODUCT CONSISTENCY TESTING

One of the methods used to evaluate chemical durability of treated hazardous and radioactive waste is the Product Consistency Test (PCT). The PCT test methods are described by the American Society for Testing and Materials (ASTM) Designation C 1285-97. The PCT test is essentially an extraction that is performed on a crushed sample of the vitrified product. The extraction procedure emulates long-term exposure to worst-case environmental conditions by presenting a large surface area of the treated product to a relatively corrosive extraction medium. The extraction medium is then analysed to determine the rate of elemental release from the product to the medium. The measured elemental release rates can then be compared to those from other treated waste products and a determination of relative product quality can be made.

2.1.1 TEST PROCEDURES

Two samples of converted products were selected for PCT testing. The two samples were collected at random and were arbitrarily named Samples A and B. They were prepared by statistically splitting the material. Splits for each of the samples were analysed for bulk chemistry using X-ray fluorescence and other splits were prepared for PCT testing by crushing and rinsing. The crushed samples were then subjected to particle size analysis. PCT testing was performed using deionized water as an extraction fluid in non-reactive vessels at a temperature of 90º C. The pH of the extraction fluid was 7.0 at the initiation of the tests. The samples were exposed to the extraction fluid for a period of 7 days after which the fluid was subjected to elemental analysis.

2.1.2 TEST RESULTS

Whole rock analyses were performed on the vitrified product samples using X-ray florescence (XRF) for 13 metal oxides. Inductively coupled plasma spectroscopy (ICP) analysis was also performed on the leachant from the PCT tests for 27 elements. The concentrations of the elements in the leachant were then normalized relative to composition and surface area of the product. Normalizing the results facilitates a comparison between elements. The normalized value is obtained by dividing the product of the blank-corrected concentration of an element in the leachant and the volume of the leachant by the product of the mass fraction of the element in the sample and the surface area per unit mass of the crushed sample particles in the test.

The normalizing formula [1] is:

Where: $$NR_e = \frac{(C_{es} - B_e) \times V_s}{f_e \times SA_s \times m_s} = \frac{(C_{es} - B_e)}{f_s \times m_s \times (SA_s \div V_s)}$$

NR_e = normalized release of element *e*, from sample *s*

C_{es} = concentration of element *e* in leachate from sample *s*

B_e = concentration of element *e* in leachate from blank (detection limit for all analyses)

V_s = initial volume of leachant in vessel containing sample *s*

f_e = average mass fraction of element *e* in the sample = (mass fraction oxide in material) x (atomic weight of metal in oxide)/(atomic weight of oxide),

m_s = original mass of sample *s*

SA_s = surface area per unit mass of sample *s*

The surface area per unit mass is found by the following equation:

$$SA = \frac{4\pi r^2}{4/3\pi r^3 \times 2.5g/cm^3}$$

This calculation assumes a mean diameter of spherical particles. A grain density of 2.5 g/cm^3 was used for the calculation based upon measurements of similar products. The mean diameter of the product particles used in the test was the material passing the #100 sieve but caught by the #200 sieve (0.075mm to 0.15mm). The mean particle size for the two samples was 0.113mm.

The final normalized release values are expressed in g/m^2 (grams of element released per square meter of surface area).

Eight elements are represented. These include the elements for which detectable analytical results from the treated product and from the leachant from both groups of samples were obtained. Normalized release rate calculations and comparisons cannot be performed without both analyses from both groups and the concentration in the treated products needs to be above detection limits.

The acceptance criteria for waste glass was defined in the U.S. by releases measured with the PCT test [2]. The releases of Na and Si are considered the best indicators of product quality. For PCT testing in deionized water at 90°C for 7 days, Na and Si releases should be less than 6.67 and 1.96 g/m2 respectively.

The results of these tests can be compared to PCT tests previously performed on vitrified radioactive samples with similar composition [3]. The PCT Tests previously performed included 7-day and 28-day tests at 90°C and 26°C. Table V shows the results of the prior PCT tests performed on vitrified products and those performed on the converted ACM.

Table V shows that the PCT results derived from the ARI samples (ARI A & B) are 1 to 2 orders of magnitude better than the U.S. established criteria of 6.67 and 1.96 g/m2 for Na and Si respectively. Furthermore, the results are comparable to PCT tests performed on vitrified radioactive waste from Australia (Vit Samples) having similar composition. Table VI compares the data presented in Table VI in graphic form.

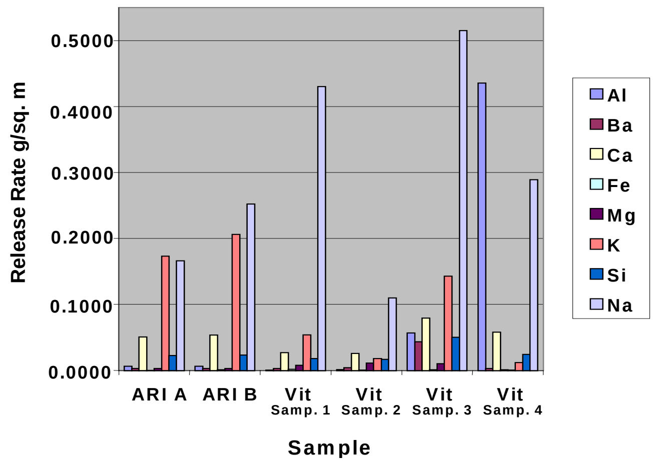
Table V. Comparison of ARI PCT Results with that of Vitrified Radioactive Products

	Vit 1	*Vit 2*	*Vit 3*	*Vit 4*	*ARI-A*	*ARI-B*
	Release Rates g/m^2	*Release Rates* g/m^2	*Release Rates* g/m^2	*Release Rates* g/m^2	*Release Rates* g/m^2	*Release Rates* g/m^2
Al	0.0004	0.0013	0.0568	0.4352	0.0061	0.0061
Ba	0.0030	0.0041	0.0434	0.0028	0.0027	0.0032
Ca	0.0270	0.0260	0.0794	0.0579	0.0510	0.0536
Fe	0.0016	0.0003	0.0008	0.0010	0.0003	0.0010
Mg	0.0079	0.0110	0.0104	0.0006	0.0030	0.0032
K	0.0540	0.0180	0.1429	0.0120	0.1821	0.2166
Si	0.0180	0.0170	0.0505	0.0242	0.0225	0.0232
Na	0.4300	0.1100	0.5150	0.2888	0.1659	0.2522

The volume of the treated product was measured and

Table VI

PCT Performance Comparison, Converted & Vitrified Products



realistic operational estimates for ongoing processing, it should be assumed that a system for the DOE would be designed to address a specific waste type and that it would be equipped with heat recovery to economize fuel.

Operational estimates were made using the figures shown in Table VII. Using the assumptions presented in Table VII, a 37 ton/day system can be operated for a price of $174/ton. This price can be reduced with an increase in system scale, waste energy value and/or improvements in throughput capacity. Economic studies coupled with engineering evaluations of larger scale systems clearly show that processing costs of near $100/ton can achieved.

Table VII. Assumptions for Cost Estimates

Item	*Assumption*
System Size	37 tons/day
System Type	Direct Fired w/Heat Recovery
Scrubber Type	Dry Lime
Capitalization	10 yr., linear
Crew Size	3
Operational Efficiency	80%
Operational hours	24 hr/day
Waste to be processed	Asbestos & Metals

The cost of thermochemical conversion processing was compared to the cost of land disposal in Europe and in the United States. Table VIII presents land disposal costs identified in several European countries and on the west coast of the U.S.

Table VIII. Land Disposal Costs in Europe and the U.S.[1] [4]

Country	*Cost: US$*	*Cost: Euros*
United States [5]	159	179
Ireland	267	300
Ireland (Export)	516	580
Austria	57-130	64-146
Netherlands	115	129
Belgium	68-81	76-91
Germany	25-51	28-57
Denmark	21-33	24-37

The cost figures in Table VIII exclude landfill and other taxes where applicable and show that the cost of thermochemical processing of asbestos is comparable to land disposal costs in many European countries once disposal taxes are taken into account. By using a large processing facility (i.e., >100 tons/day), thermochemical processing could prove to be significantly less expensive than land disposal. Thus, thermochemical treatment of asbestos waste appears to have economic benefits as well as the benefits derived from the reduction in volume, reduced landfill usage, production of a recyclable product and reduced liability.

4.0 CONCLUSIONS

ARI Technologies, Inc conducted a series of tests during which asbestos-containing material from the Department of

Energy installation at Savannah River was processed. The objectives of establishing a site agreement with Savannah River, transporting the ACM to Tacoma, converting the ACM into non-asbestos, non-hazardous aggregate and evaluating process economics were met. In addition to the required objectives, ARI also processed some of the ACM with spiked quantities of RCRA metals and surrogate radionuclides to evaluate the ability of the process to immobilize these metals. These additional tests were also successful.

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 economically,
- The technology is effective on organic wastes (such as PCBs), inorganic wastes (such as asbestos) and can immobilize metals and surrogate radionuclides,
- Modifications to the system used in this project reduced the residence time required for complete conversion to take place from 50 minutes to 20 minutes at full scale,
- Additional tube furnace tests showed that conversion can be accomplished in less than 10 minutes
- Thermochemical conversion provides treatment effectiveness equivalent to vitrification for a lower cost for certain wastes,

The U.S. Department of Energy recently published an Innovative Technology Summary Report (ITSR) [6] wherein the following statement is made:

"Thermochemical conversion is an effective and economic method of processing a variety of DOE-generated wastes.

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."

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[4] United Kingdom Waste Management Strategy Unit Report, Waste Not Want Not, November 2002

[5] Quoted price of \$88/yd^3 at Waste Management's disposal facility in Arlington, Oregon.

[6] U.S. Department of Energy National Energy Technology Laboratory (NETL), Tech I.D. 3114, Technology Deployment for Asbestos Destruction, September 2002.

FOOTNOTES

[1] Information was converted to U.S. dollars, Euros & metric tons for ease of comparison. European costs do not include the EU landfill levy, local taxes, packaging, solidification or transportation costs. The Irish costs refer specifically to asbestos disposal. The disposal costs for the other European countries are the ranges of landfill charges for each country. Costs for asbestos disposal in these countries is typically at the high end of the range and in some cases even higher. U.S. volumetric disposal quotes were converted to tons based upon measured densities of 0.5 ton/m^3 (U.S. costs only).
