MEMORANDUM

SUBJECT:  Evaluation of Application of ARI Technologies, Inc.'s Thermochemical Conversion Technology to Treat Asbestos, PCBs, and Metals Contaminated Soils and Sediments from the Raymark Industries, Inc. Site

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INTRODUCTION

EPA Region I – New England is conducting an evaluation of remedial alternatives for asbestos, metals and PCB contamination at the Raymark Industries, Inc. site. The local community has requested that a thermochemical conversion technology (TCCT) be considered. Region I has requested assistance from the Technology Assessment Branch (TAB) in evaluating the TCCT developed by ARI Technologies, Inc. (ARI). We have completed a review of all available literature on the technology, have reviewed and commented on interrogatories with the technology vendor, have had several long discussions with the vendor, and have sought input from other Federal agencies that have been part of various demonstrations of the technology. Provided in this memorandum are our observations, comments, and issues to be considered on the use of the technology at the Site.

SUMMARY OF CONSIDERATIONS

- ARI’s TCCT has been demonstrated at pilot-scale projects for typical asbestos-containing materials but has not been used at full-scale.
- ARI’s TCCT achieves temperatures sufficient for the total conversion of asbestos materials into non-hazardous material.
- Asbestos containing soils and sediments found at the Raymark Industries, Inc. Site are very different from the asbestos-containing materials that have been the subject of TCCT treatment to date.
- ARI’s TCCT can be expected to achieve some level of metals immobilization. Verification of actual immobilization performance on a variety of Raymark Industries, Inc. contaminated materials would be required.
- The large scale TCCT unit(s) proposed and likely needed for the wide-spread Raymark soil waste would not be mobile. Thus, central processing at a fixed location would be necessary. ARI’s TCCT operations would require sophisticated monitoring not only of stack emissions for asbestos but also monitoring of other unit processes.
As the vendor notes, Raymark soil waste specific bench-scale studies will be important. We do not concur with the suggestion that bench-scale studies alone will be sufficient to allow scale up to full-scale pre-processing and thermochemical treatment processes. Significant pilot-scale testing will be required to establish performance data, accurate cost and reliability estimates, and long-term reuse of the treated end-product. Process throughput per se is not as important as extended operation encompassing waste streams representing the important differences among wastes from multiple operational units.

ARI has previously received approvals from EPA and state agencies to process asbestos and PCB containing wastes. The PCB approval has expired. Given the scale of proposed asbestos treatment units, regulatory review of existing approvals is desirable. We mention these factors merely as likely administrative considerations rather than as major impediments.

BACKGROUND

Asbestos and Asbestos Containing Material (ACM)

Asbestos is a geologic term used for a group of naturally occurring silicate minerals that form fibers during crystallization. There are two classes of asbestos: serpentine asbestos, which is more common, and amphibole asbestos. Regulated asbestos includes chrysotile, the asbestiform member of the serpentine group, and five members of the amphibole mineral group, the asbestiform varieties of riebeckite (commercially called crocidolite), cummingtonite-grunerite (commercially called amosite), anthophyllite, actinolite, and tremolite. These regulated minerals may also have a non-fibrous form in which they do not exhibit an asbestiform nature and are not regarded as asbestos. Chrysotile is by far the most common type of asbestos used for commercial purposes. It represents over 90% of the world's production of asbestos, as well as 95% of the asbestos used for commercial purposes in the United States.

Asbestos-containing material (ACM) is defined by the Asbestos NESHAP (National Emission Standards for Hazardous Air Pollutants) as any material containing more than one percent (1%) asbestos as determined using polarized light microscopy (PLM). Common examples of ACM include, but are not limited to: pipe and boiler thermal insulation, sprayed on fireproofing, troweled on acoustical plaster, floor tile and mastic, floor linoleum, asbestos cement board and shingles (transite), roofing materials, wall and ceiling plaster, ceiling tiles, and gasket materials.

Asbestos-Containing Wastes at the Raymark Industries, Inc. Site

The waste at the Raymark Industries, Inc. Site does not match the typical description of ACM. Raymark Industries, Inc was a manufacturer of friction materials containing asbestos and non-asbestos materials, inorganics, phenol-formaldehyde resins, and various adhesives. Primary products were gasket material, sheet packing and friction materials including clutch facings, transmission plates, and brake linings. As a result of disposal of manufacturing wastes, soils at the Site have been primarily contaminated with asbestos, PCBs, and metals. Raymark soil waste has been characterized by EPA as containing lead above 400 parts per million (ppm), asbestos (chrysotile only) greater than 1 percent, and either copper above 288 ppm or polychlorinated biphenyls (PCBs) (Aroclor 1268 only) above 1 ppm.

Traditional Handling and Disposal of Asbestos Containing Material

ACM from typical abatement activities in the United States has been disposed in offsite landfills. ACM can be disposed at municipal solid waste (MSW) landfills or construction and demolition (C&D) landfills that have the appropriate procedures in place for handling these materials; i.e., compliant with the Asbestos NESHAP (40 CFR 61.154) and any applicable state, local or tribal laws. In some cases, the ACM is consolidated and landfilled onsite. For ACM at CERCLA sites, provided that asbestos is the
only contaminant being managed, the substantive standards of 40 CFR 61.154 would be considered for ACM waste disposal. If the ACM being managed contains other contaminants of concern, other regulations may govern the management of such materials, such as the RCRA hazardous waste Subtitle C regulations for landfill covers.

TECHNOLOGY DESCRIPTION

Methods for permanent destruction of asbestos waste have been developed as an alternative to landfilling or onsite consolidation. One of the methods available for the destruction of asbestos-containing wastes is the thermochemical conversion technology (TCCT) developed and offered by ARI Technologies, Inc. Besides the conversion of asbestos, ARI's TCCT has demonstrated the capability to destroy organic wastes such as PCBs and, to some extent, to immobilize metals.

**Asbestos Treatment**

ARI's TCCT process includes bulk size reduction of asbestos waste material, application of a fluxing solution to the waste, and heating of the waste to approximately 1,200°C for approximately 20 - 40 minutes. The following description of the thermochemical conversion of asbestos is taken verbatim from ARI's 2007 report titled *Ten-Day Asbestos Destruction Demonstration using Thermochemical Conversion Technology*. The report details a 10-day operational demonstration of ARI's TCCT for a consortium of four Japanese companies.

"Many asbestos minerals are part of the serpentine group of hydrated silicates and all asbestiform minerals have a structural resemblance to the serpentine minerals. Although the serpentine minerals are physically fibrous, they are actually layered silicates with the approximate composition of Mg₂Si₂O₅(OH)₄. In simplified terms, serpentine minerals consist of a pseudo-hexagonal network of SiO₄ tetrahedra linked to a brucite layer. The lateral dimensions of the ideal octahedral and tetrahedral components of a serpentine layer do not match well. The various structures and textures of the serpentine family of minerals correspond with the different ways of overcoming this mismatch. Thus, serpentine minerals exhibit internal strains caused by molecular discontinuities of which one can take advantage to encourage conversion to other non-serpentine minerals.

Serpentine minerals will expel structural water (hydroxyl groups) at between 700° and 800°C. However, this reaction is slow even at considerably higher temperatures. This slow reaction coupled with the superior insulating properties of the fibrous forms (asbestos) make them particularly difficult to destroy thermally. Without the presence of fluxing agents, conversion can take nearly two hours even at temperatures as high as 1,200°C in particles as small as 2 in. in diameter. Larger particles take longer due to slow heat transfer.

By introducing a fluxing solution, homogeneous intimate contact between the flux cations and asbestos fibrils can be attained. The absorbent nature of friable and asbestos cement products assists in the rapid delivery of the solution to asbestos fibrils.

At a temperature of about 1,200°C these cations will react rapidly with other ions in the asbestos fibrils. The specific type and order of the reactions are not well understood but the result is an accelerated solid solution reaction. This reaction ... results in the expulsion of hydroxyl groups, collapse of the brucite layer and destruction of fibrous morphology. The result is the formation of new volcanic type minerals including olivine, wollastonite, diopside and other pyroxenes depending upon the chemistry of the feed. This reaction takes place without melting the material (and thus without having to overcome the heat of fusion)..."
**PCB destruction**

High temperature incineration has been one of the most applied remediation technologies for the destruction of PCBs. It is a high temperature (870 °C to 1,200°C) destructive ex situ treatment. The waste and/or contaminated soil are fed into an incinerator under controlled conditions and the high temperatures in the presence of oxygen volatilize and combust the contaminants into innocuous substances.

While ARI’s TCCT was developed for the conversion of asbestos into non-hazardous material, the destruction of hazardous organic compounds also occurs through the process. The nominal operating temperature for ARI’s TCCT is at the upper range of those required to destroy PCBs. Pyrolysis of the organic compounds takes place within the rotary hearth of the TCCT unit where the temperature is maintained at ~1,200°C. 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 oxidation unit, the off-gases are cooled and scrubbed for particulates and acid components that might be present.

**Metals**

ARI’s TCCT is a high-temperature (~1,200°C) process that results in sintering of asbestos waste to produce a mixture of glass and crystalline material without complete melting. ARI reports that the glass and crystalline products are produced through a process of accelerated solid solution and small amounts of partial melting. Metals are bound into a silicate matrix with strong ionic and covalent bonds either as part of a mineral structure or in silicate glass.

ARI reports that lead readily forms a stable glass with SiO₂ (silica), is highly reactive in glass chemistry, and suppresses the temperature required for glass formation. Thus, lead is incorporated into the silicate glass portion of the treated end-product. This glass portion has been referred to as glass blebs which are readily apparent in electron photomicrographs of the treated end-product. The closest natural analogue to the glass produced in TCCT is obsidian (volcanic glass), a material known to last for thousands to millions of years.

According to ARI, the ability of TCCT to immobilize metals is dependent upon the concentration of glass-forming ions in the waste; the most significant of which is silicon. In general, if the normalized composition of the waste contains a minimum of 40% to 50% SiO₂, the treated product will effectively immobilize metals in a product that possesses superior chemical durability and leach resistance.

**PREVIOUS EXPERIENCE**

In the early 1990s, ARI’s TCCT was developed and passed through the “proof of principle” phase. Since that time, ARI has conducted TCCT demonstration projects for the U.S. Department of Energy, the U.S. Navy, and a Japanese consortium. A brief summary of these projects is included below.

- **1996: U.S. Department of Energy’s Hanford Reservation**
  
  **Waste Material:** 430 yd³ of ACM
  
  The ACM consisted of ceiling popcorn, spray insulation, woven cloth goods, low-temperature boiler insulating board, refractory insulating board, electrical products fiber wrap (from electrical power cord coverings), cement asbestos board, fiber-reinforced calcium silicate pipe lagging, asbestos cardboard lagging, incidental soil with ACM, vinyl asbestos tile and several grades of asbestos paper and millboard products.
  
  **Process Throughput:**
  
  Data unavailable
Results:
All treated waste was found to be asbestos free and no asbestos fibers were identified in the off-gas from the process monitoring.

- **2000: Puget Sound Naval Shipyard Asbestos & PCB Program**
  
  **Waste Material:** 25 tons of ACM  
  The ACM was collected from facility abatement and ship maintenance and repair projects. ARI spiked selected quantities of ACM with high concentrations of PCBs.
  
  **Process Throughput:**  
  Data unavailable
  
  **Results:**  
  The process was shown to exhibit the required destruction and removal efficiency (DRE) for PCBs of >99.9999% and the emissions for the process surpassed the federal and local standards for PCBs, dioxins, and furans. No asbestos fibers were detected in the treated product.

- **2002: U.S. Department of Energy’s National Energy Technology Laboratory (NETL)**
  
  **Waste Material:** 10 tons of ACM  
  The ACM was collected from abatement projects at DOE’s Savannah River Site. The ACM contained friable asbestos and cementaceous asbestos (transite). During the demonstration, the ACM was spiked with cadmium, lead, barium, arsenic, and radioactive surrogates cesium and cerium.
  
  **Process Throughput:** 800 lbs. of ACM per hour, which is roughly equivalent to 10 tons per day
  
  **Results:**  
  No asbestos fibers were found in any of the treated product samples. The treated products from the samples spiked with Cd, Pb, Ba, and As were subjected to TCLP testing to determine if thermochemical conversion would immobilize metals to the extent that the treated product would meet land-ban standards. In general, the TCLP results were about 1 order of magnitude better than EPA requirements for Cd, Pb, and As. The Ba results were 2 orders of magnitude better than EPA requirements.

- **2007: Consortium of four Japanese Companies**
  
  **Waste Material:** 65.2 tons of ACM  
  The ACM was collected over a period of several months from asbestos abatement contractors in the Northwest U.S. The ACM contained cement asbestos board, pipe lagging, roofing paper, insulating board, and spray-on insulation. Lab analysis by TEM, PLM, and/or XRD indicated that the ACM contained 1.5% to 14.48% of chrysotile, amosite, and/or crocidolite.
  
  **Process Throughput:** 7.5 to 10 tons of ACM per day
  
  **Results:**  
  All asbestos analyses on treated product resulted in non-detectable levels of asbestos.

- **Full-scale commercialization**
  
  To date, none of the demonstration-scale projects has led to the development of a full-scale TCCT unit or the deployment as part of a full-scale ACM remediation in the US. Efforts to discuss the issue of lack of commercialization with DOE and DOD sponsors have met with limited success. Likewise, we have not been able to gain any visibility into the nature and extent of the ACM problem at DOE or DOD installations. The vendor reports promising developments regarding interest in the TCCT in Europe, however to date there are no full-scale units or projects.
EPA APPROVALS

In the late 1990's, EPA approved ARI Technologies, Inc.'s thermochemical conversion technology for asbestos conversion and PCB destruction. EPA’s Stationary Source Compliance Division reviewed and approved Asbestos Conversion Systems, Inc.'s (former name of the present ARI Technologies, Inc.) application to construct mobile asbestos conversion systems. As long as the mobile units were constructed and operated according to the conditions specified in the application, no emissions violation of the NESHAP standard for asbestos conversion would occur. This approval has no expiration but ARI may be required to reapply for EPA approval if the operation of a newly constructed TCCT unit would deviate from the conditions specified in the historical application, subject of course to the interaction between CERCLA and other statutes.

EPA’s National Program Chemicals Division (NPCD) granted ARI Technologies, Inc. a PCB Disposal Approval to operate the mobile Thermal Chemical Conversion Unit (TCCU) as a polychlorinated biphenyl (PCB) thermal disposal unit. The approval authorized ARI to dispose of PCBs in ACM, soil and other solid matrices, and liquid PCBs nationwide. This approval has since expired and ARI has not attempted to get further approval since it has no existing contracts for PCB destruction.

RAYMARK INDUSTRIES, INC. SITE CONSIDERATIONS

The vendor has expended considerable good faith effort in responding to interrogatories and in providing estimates regarding likely cost and performance of the ARI thermochemical conversion technology. The vendor and numerous researchers have demonstrated adequate conversion of asbestos materials into non-hazardous material at the temperatures achieved by the TCCT.

Unfortunately, significant uncertainties remain regarding likely full-scale performance, given a) the major difference between scale of operations to date (10-12 tons/day) and the anticipated throughput of a full-scale unit (350 tons/day); and b) the highly, heterogeneous asbestos-, PCB-, and metals-laden mixture of soils and sediments found at the Raymark Industries, Inc. Site. While the phenol formaldehyde resin binders in the Raymark soil waste may off-set some energy input requirements, they may also pose some significant pre-processing and thermal treatment challenges. Appropriate combinations of waste separation and/or sizing unit processes have yet to be fully determined.

As discussed previously, the vendor has conducted studies beyond the lab/bench scale on behalf of the Department of Energy, the Navy, and international entities. These studies inform the vendor’s estimates, however they are not sufficient to predict performance or to anticipate all of the issues likely to be encountered in a high throughput full-scale system. These uncertainties apply to both the pre-processing and thermal treatment steps in the process. Previous experience with scaling up higher temperature technologies such as plasma arcs and vitrification to treat complex wastes is replete with examples of major surprises. Even incineration projects - an ostensibly ‘established’ technology - have experienced problems.

Building a unit of sufficient size to accurately estimate cost and performance presents the dilemma of pre-committing to full-scale use or abandoning the project after significant investment. A possible way to overcome this dilemma would be to build the first sub-unit of a modular system comprised of units substantially larger than those employed to date, but not so large as to result in the loss of inordinate costs if a fatal flaw in the technology were to emerge. This financially prudent approach unfortunately might result in some loss of economies of scale.
ANCILLARY CONSIDERATIONS

Aroclor 1268 Destruction

The most prevalent PCB at the Raymark Industries site is Aroclor 1268. A previous bench-scale treatability study for thermal treatment of site PCBs confirmed that high temperatures and a long retention time were required to remove all detectable PCBs from the Raymark soil waste. The most recalcitrant PCB was Aroclor 1268. While ARI’s TCCT has been demonstrated to operate at temperatures well above those required to destroy all PCBs, it has not been formally demonstrated to destroy Aroclor 1268. Bench scale testing will be required to determine the temperature and residence time necessary to facilitate the required destruction and removal efficiency (DRE) for Aroclor 1268.

Metals Immobilization

Beyond the ability of the technology to destroy the asbestos component of the waste, it is crucial that the technology also immobilize the high metals content reported in some of the Raymark soil waste.

A key component of the vendor’s claims for consideration rest on ability of ARI’s TCCT to render wastes non-hazardous, thus allowing either beneficial reuse or unrestricted disposal. Ability to achieve requisite mobility reductions in a high throughput operating environment across the wide spectrum of Raymark soil waste requires further verification and an adequate post-treatment monitoring regime.

The vendor has expressed some expectation of at least partly meeting metals immobilization requirements by ‘evening out’ - i.e., mixing and homogenizing - the wastes. As a practical matter, this may not be feasible as wastes are brought from different sub-units. More importantly, given the problematic nature of potential airborne asbestos releases, the presumption would seem to be to prefer to minimize the extent of materials handling. Careful consideration must be given to the feasibility and desirability of blending as a component of any remedial strategy.

In addition to the blending described above, the vendor has made representations regarding the ability of ARI’s TCCT to immobilize the metals in glass blebs without the necessity of achieving the temperatures required for vitrification (in excess of 1600°C). Metal immobilization by the technology is similar to vitrification. The difference being that during the thermochemical conversion process, the melting temperature of the waste material is never reached and therefore the material does not totally become a vitrified glass. Since the ARI process does not melt the waste or produce a completely glass end-product, the metals are believed to be incorporated into glass blebs within the overall matrix of the end-product. In order for the glass blebs to form and sufficiently immobilize metals, the Raymark soil waste to be treated must contain an adequate concentration of glass-forming ions. The waste must be composed of a minimum normalized concentration of 40% to 50% SiO₂. The SiO₂ concentration in any waste stream to be treated by ARI’s TCCT must first be determined before any determination concerning metal immobilization can be made.

Furthermore, the immobilization of metals throughout the entire treated end-product deserves considerable study to ensure the treated product’s long-term stability for potential reuse/unrestricted disposal. It is not readily apparent that the long-term mobility of metals in the treated end-product can be evaluated well by current leachability tests (TCLP). It is uncertain what the effects, over the long term, of weathering (i.e., freeze-thaw cycles, acid precipitation and infiltration), groundwater infiltration, and physical disturbance associated with uncontrolled future land use may have on the integrity of the treated end-product and the mobility of the metals.

Possible Need for Re-processing of Treated Wastes

Standard practice for ex situ thermal treatment is to conduct some level of statistical sampling of treated batches of waste. Batches which fail to achieve required cleanup goals are usually re-processed. This
may be a suitable approach for the asbestos and PCB components of the Raymark soil waste. In the asbestos case, if failure were attributable to waste particle size, additional size reduction might be warranted. A question for which we do not have a ready answer is what would be done with batches which failed metals leachability criteria.

Net Energy Production

Some of the materials presented for our review suggested the possibility that application of ARI's TCCT might, in the right situations, result in net energy production. Such a result does not seem likely at the Raymark Industries, Inc. Site. Despite the presence in at least some of the wastes of phenolic resins with potential BTU value, the majority of the wastes at the Site are described as soil and sediment contaminated mixtures, often with significant water content. As a result it is not likely that processing of the Raymark soil waste will result in net production of energy which could be returned to the grid, thus off-setting the energy costs of the project.

RECOMMENDATIONS

Despite the relatively short amount of time the Technology Assessment Branch has been involved at the Raymark Industries, Inc. Site, it is apparent that any active remedial strategy will face daunting logistical challenges which are well beyond the scope of our review of the specific ARI thermochemical conversion technology. If a decision is made to pursue use of ARI's TCCT, pilot-scale studies of significant size and substantial duration will be needed to generate a reasonably accurate idea of the performance parameters and cost aspects of the technology. Anything less will result in a situation with unacceptably large error bars.

PROGRAMMATIC CONSIDERATIONS

While the purview of the Technology Assessment Branch is primarily technical, the issue of availability of any full-scale treatment unit warrants discussion. The vendor reports that existing equipment (i.e., 10-12 ton/day unit) is currently in mothballed status, and that a 350 ton/day throughput unit would require an estimated $20M capital investment. The cost of pilot scale testing with a much smaller unit (4-ft. diameter hearth) with a low throughput is estimated by the vendor to be ~$1M. We believe, however, that a larger unit with a throughput that is comparable to a full-scale operating system would be required to evaluate the effectiveness and efficiency of the technology in treating the Raymark soil waste. The cost of the larger pilot-scale study would be substantially greater than estimated by the vendor.

Also while perhaps outside the strict purview of this technology evaluation, from a total societal investment standpoint, it is not unreasonable to ask what would be done with this equipment following completion of remedial activities. As discussed above, DOE, the Navy, and international entities have considered and even funded smaller scale treatment unit development for ARI's thermochemical conversion technology, but none to date have supported larger-scale development or identified additional waste streams. We have had email discussions on the matter with some Navy counterparts but we have received only limited feedback at this time. Similarly, we have been unsuccessful in obtaining information regarding future EPA asbestos remediation needs.

END NOTE

This evaluation was intended to provide Region I staff with input to inform decision-making regarding the ARI Technologies, Inc. thermochemical conversion technology to address the asbestos, PCBs, and metals contaminated soils and sediments at the Raymark Industries, Inc. Site. Time and resource
constraints precluded the preparation of a Focused Feasibility Study (FFS) level analysis. In possible furtherance of such an analysis, we have compiled available resources included as an appendix.
APPENDIX
PERTINENT DOCUMENTS


