MIXED WASTE TREATMENT COST ANALYSES FOR A RANGE OF GEOMELT VITRIFICATION PROCESS CONFIGURATIONS

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ABSTRACT

GeoMelt is a batch vitrification process used for contaminated site remediation and waste treatment. GeoMelt can be applied in several different configurations ranging from deep subsurface in situ treatment to aboveground batch plants. The process has been successfully used to treat a wide range of contaminated wastes and debris including: mixed low-level radioactive wastes; mixed transuranic wastes; polychlorinated biphenyls; pesticides; dioxins; and a range of heavy metals.

Hypothetical cost estimates for the treatment of mixed low-level radioactive waste were prepared for the GeoMelt subsurface planar and in-container vitrification methods. The subsurface planar method involves in situ treatment and the in-container vitrification method involves treatment in an aboveground batch plant.

The projected costs for the subsurface planar method range from \$355-\$461 per ton. These costs equate to 18-20 cents per pound. The projected cost for the in-container method is \$1585 per ton. This cost equates to 80 cents per pound. These treatment costs are ten or more times lower than the treatment costs for alternative mixed waste treatment technologies according to a 1996 study by the US Department of Energy.

INTRODUCTION

GeoMelt is a batch vitrification process used for contaminated site remediation and waste treatment. GeoMelt can be applied in several different configurations ranging from deep subsurface in situ treatment to above ground batch plants. The process has been successfully used to treat a wide range of contaminated wastes and debris including: mixed low-level radioactive wastes; mixed transuranic wastes; polychlorinated biphenyls; pesticides; dioxins; and a range of heavy metals.

The GeoMelt in-container vitrification method was used in Japan to treat an abandoned industrial waste incinerator that was heavily contaminated with dioxins, furans and PCBs. The incinerator was dismantled and decontaminated to the extent possible and GeoMelt was used to treat the residual wastes including steel, ash, brick and decontamination wastes.

In Australia, the design is nearly finalized for a batch plant that will treat a 60,000-drum inventory of concentrated hexachlorobenzene wastes. The concentrated chlorinated organic waste will be mixed with soil (1 part waste to 2 parts contaminated soil) to facilitate treatment.

In the US, the subsurface planar method was recently applied in a demonstration project to treat a portion of a mixed low-level radioactive liquid waste adsorption bed at the Los Alamos

National Laboratory's MDA-V site. That project was funded by the US Department of Energy's Subsurface Contaminants Focus Area.

The range of GeoMelt process configurations being used and the types of wastes being treated are extremely varied. The treatment costs differ depending on the configuration being employed and the type and volume of wastes being treated. This paper reviews the primary operating configurations and provides a cost analysis summary for each operational configuration.

AMEC

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GEOMELT TECHNOLOGY DESCRIPTION

The GeoMelt process represents a group of vitrification technologies that can be configured in various ways to meet a wide range of treatment requirements. All of the GeoMelt technologies involve the electric melting of contaminated soils and debris to result in the destruction, removal or permanent immobilization of contaminants.

The melting process is initiated within a waste or soil mixture. Electrical power is directed to the treatment zone via graphite electrodes and regulated to maintain the desired melt rate. The melt temperature typically ranges from 1400-2000 degrees C depending on the materials being treated and the particular process configuration. The melt grows downward and outward until the electric power is shut off once the target waste volume has been treated. Melt rates for full-scale treatment plants approaching 100 tons per day can be achieved depending on the configuration of the equipment and the material being treated. Individual melts of roughly 1,000 tons in size can be produced in an in situ treatment configuration.

Organic contaminants such as dioxins, pesticides and polychlorinated biphenyls (PCBs) are destroyed via pyrolysis and dechlorination reactions at elevated temperatures in reducing conditions around the melt. No organic contaminants remain in the melt due to the inability of organics to exist at the temperatures involved. A broad range of organic contaminant types has been successfully treated in commercial operations. The US Environmental Protection Agency has determined that PCBs do not migrate from the treatment zone into surrounding soils during GeoMelt processing and the EPA does not require surrounding soils to be sampled for such contamination [1]. The destruction and removal efficiencies (DRE) achieved during commercial operations for organic species are typically greater than 99.9999%. This DRE includes the percentage destroyed by the melt (typically 90-99.99%) and the percentage destroyed and/or removed from the off-gas stream by the off-gas treatment equipment. High concentrations of organics can be accommodated by the process. Waste loadings of up to 33-wt% in soil have been demonstrated for chlorinated organics such as hexachlorobenzene [2]. Weight percent concentrations of pesticides in soil, such as DDT, have also been successfully treated.

The melt incorporates most heavy metal and radionuclide contaminants resulting in permanent immobilization in the resulting vitrified product. Non-volatile metals and radionuclides such as uranium and plutonium have a high degree of retention in the melt (e.g., 99.999%). For semi-volatile radionuclides like cesium, a number of tests and demonstrations, including full-scale operations, have demonstrated the retention of cesium in the melts as being very high (typically 99-99.99% [3,4]. The degree of retention in the melt of semi-volatile heavy metal contaminants such as lead, cadmium and arsenic is quite high (generally around 80-90%). Volatile metals, such as mercury, are released from the melt and captured by the off-gas treatment system. Relatively high contaminant concentrations of heavy metals and radionuclides can be accommodated by the process.

The vitrified product normally consists of a mixture of glass and crystalline materials and often has an appearance similar to volcanic obsidian. Following the treatment of mixed low-level radioactive or hazardous wastes, the vitrified product will not be characteristic waste (i.e., it will not exhibit characteristics of RCRA wastes). The product is typically five to ten times stronger than concrete and is extremely leach resistant. The vitrified product readily satisfies the requirements of the US Environmental Protection Agency's (EPA) Toxicity Characteristic Leaching Procedure (TCLP). The vitrified product is normally 10 or more times more durable and leach resistant than typical borosilicate glasses used to immobilize high-level nuclear waste. The durability and leach resistance of the glass is due to a high concentration (up to 90 weight %) of glass formers (SiO_2 and Al_2O_3). A variety of leach tests of the vitrified product from a number of GeoMelt projects have been conducted including vitrified product containing both uranium and plutonium. Leach data from these tests indicate that the normalised leach rates for the vitrified products are extremely low (typically <0.1 g/m^2day) for all oxide species and in most cases approach 0.01-g/m^2 day [3,4,5,6,7]. These values easily satisfy leach criteria typically used to evaluate the performance of nuclear waste glasses. Data from long-term leach tests (>4 year leach duration) indicate the release rates of U and Pu decrease markedly in the long-term [6].

GeoMelt can simultaneously accommodate complex mixtures of contaminant types including organic and inorganic contaminants. Large amounts of debris can be accommodated in individual melts. For example, in situ melts have been used to treat on the order of 50 tons each of bitumen and concrete and 20 tons of steel. Types of debris treated in prior commercial operations include concrete, bitumen, bricks, steel, wood, plastic and automobile tires.

Off-gases that evolve from the melt are collected in a steel containment hood and directed to an off-gas treatment system. The off-gas treatment steps vary depending on the particular requirements of the project but generally consist of an initial step of particulate filtration followed by quenching, wet scrubbing, two stages of high efficiency particulate filtration, and carbon adsorption or thermal oxidation.

The amount and type of secondary wastes generated by GeoMelt operations depend on the configuration of the process system and the nature of the waste materials being treated. Solid wastes, such as filters and used protective clothing, can be treated by placing such materials into the next batch to be treated. Scrub solution is the main secondary waste generated by the process but that is generated only for those projects that require wet scrubbing.

The original GeoMelt technology is in situ vitrification wherein contaminated soils and wastes are treated in place, in the ground. This base technology has been developed into other configurations that allow a wider range of treatment applications. The primary GeoMelt treatment configurations used today are subsurface planar in situ vitrification for in situ treatments and in-container vitrification (ICV) for aboveground batch plant processing. These two methods are illustrated in Figure 1. Although other treatment configurations have been used in past projects, these two configurations represent AMEC's current market focus. The original GeoMelt technology, in situ vitrification (ISV), is no longer the preferred approach because the newer methods offer significant advantages over conventional ISV.

The *Subsurface Planar* configuration is used to treat subsurface contamination in situ, including buried waste or structures such as buried tanks. In addition to allowing the melts to be started well below grade, in some instances below the contaminated zone, the two planar melts that are formed grow horizontally together attacking the wastes and structures from the sides. Waste materials located above the planar melts subside down into the melts during treatment effectively providing a bottoms-up type of treatment approach. Subsurface planar has been demonstrated to be a more effective method for treating such wastes compared to the original ISV method. The planar technique was recently used to treat a portion of an inactive liquid waste adsorption bed at the US Department of Energy's Los Alamos National Laboratory site [7,8]. The technique has also been demonstrated at full-scale for the treatment of buried steel tanks containing simulated wastes [9].

The *In-Container Vitrification (ICV)* treatment configuration has been used in Australia and Japan and is being developed for US Department of Energy and commercial applications. The batch technique involves staging and treating wastes in refractory-lined steel containers. The containers can vary in size and shape from 55-gal drums to roll-off boxes. After each batch is treated, the melted waste is allowed to cool and solidify in the container. The solidified waste is then removed from the container and the container reused. Alternatively, the container can be disposed after each melt. After each batch of waste is treated, the vitrified waste solidified and the off-gas hood removed, a lid is placed on the container and the container with the vitrified waste is transported to the disposal site.

SUMMARY OF SELECTED PROJECTS

Remediation of an Industrial Waste Incinerator

An abandoned industrial waste incinerator located in the Wakayama Prefecture in Japan was found to be heavily contaminated with dioxins, furans and PCBs from past waste treatment operations. The GeoMelt ICV process was used to remediate the associated wastes. The project involved dismantling the incinerator components and decontaminating them to the extent possible. The wastes were then treated with the GeoMelt process. These wastes included ash, brick, steel, soil and decontamination residues. A total of 36 batches were successfully treated using the GeoMelt process.

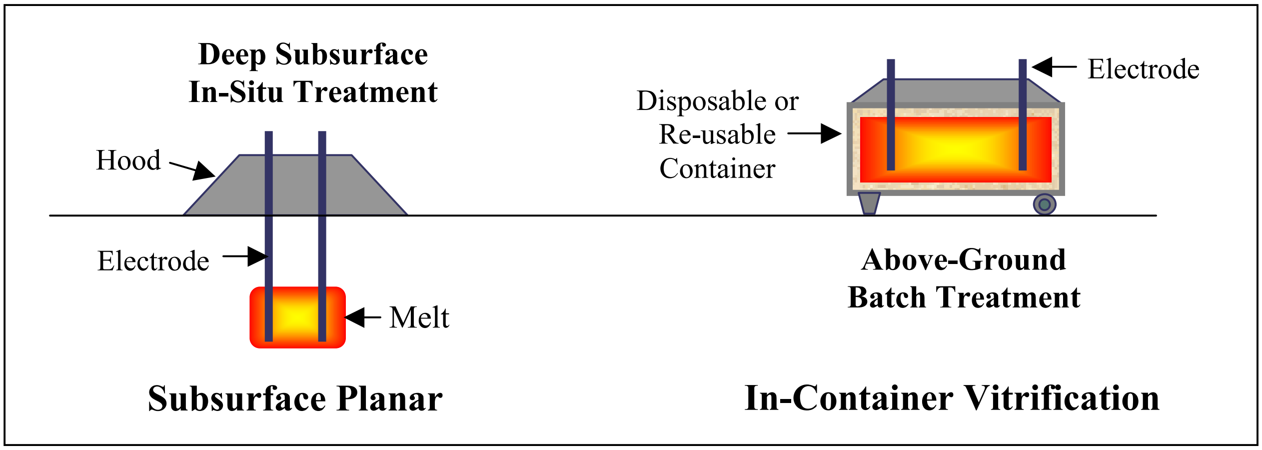

Fig. 1. Diagram showing primary GeoMelt treatment configurations.

Hexachlorobenzene Waste Demonstration Project

A demonstration project in Australia was undertaken in support of a national strategy for the management of scheduled wastes [10]. The objective of the project was to evaluate the treatment effectiveness of the GeoMelt ICV process for the treatment of concentrated hexachlorobenzene (HCB) wastes. The drummed HCB waste primarily consists of approximately 90% hexachlorobenzene. However, each drum of waste also includes weight percent concentrations of other organo-chlorines, including polychlorinated biphenyls (PCBs), and gram quantities of dioxins and furans (primarily dibenzo-p-dioxins and dibenzofurans at concentrations of 10-100 ng/g based on the international toxicity equivalent factors). The project involved a series of GeoMelt ICV demonstrations with HCB waste concentrations in soil up to 33-wt%. The project provided an opportunity to vary equipment and operational parameters to determine the most effective treatment configuration for the HCB waste. Results from the HCB demonstrations established that the GeoMelt process effectively treated the HCB waste. Destruction efficiencies of >99.9999% were achieved [2]. The demonstration project was successful and a design for a full-scale treatment plant to treat the 60,000-drum inventory of HCB waste is currently being finalized.

Demonstration Treatment of an Inactive Mixed Radioactive Liquid Waste Adsorption Bed

An evaluation of the Subsurface Planar method was conducted in 1999 and 2000 to determine the effectiveness of the process as a potential remedy for treatment of the mixed-waste-contaminated adsorption beds at the US Department of Energy's Los Alamos National Laboratory (LANL) site [7,8]. The MDA-V site was the focus of the demonstration program. Adsorption bed 1, which is a cobble and gravel-filled pit, is part of a larger system of inactive adsorption beds at the site that received contaminated laundry water and waste from plutonium research and metal production operations. Samples of the cobble area within the bed indicated up to 1,000-pCi/g plutonium 239/240. The project involved the performance of two large-scale demonstration melts. The first demonstration, termed the "cold" demonstration, was performed in an uncontaminated, simulated adsorption bed in April 1999. The cold demonstration was conducted to gather initial data to optimize the performance and technical value of the subsequent radioactive demonstration. The second demonstration, involving the treatment of a portion of the actual adsorption bed, was successfully performed in April 2000. The melt was initiated below the bed at a depth of approximately 3-4 meters below grade. The treatment depth achieved was >8 meters and the resulting vitrified monolith had a mass of approximately 500 tons. Importantly, the degree of retention of the radionuclides in the melt was extremely high as there was no contamination detected on the inner surfaces of the containment hood, on the high efficiency particulate pre-filters used to filter off-gas or in the off-gas piping. Sampling and analysis of the vitrified monolith is planned for completion in 2002.

COST ANALYSES

The following section summarizes cost analyses prepared for the subsurface planar and in-container vitrification (ICV) methods for the treatment of low-level radioactive mixed waste contaminated soil. The assessments are based on the assumption of routine commercial operations. The cost analysis for the subsurface planar method is adapted from a more detailed analysis completed for the US Department of Energy's Subsurface Contaminants Focus Area following the LANL application [7].

Factors Influencing Costs

The treatment costs for either GeoMelt method depend on a number of factors. A list of the most common factors that influence costs include:

- Equipment utilization efficiency
- Waste loading (for ICV)
- Waste volume
- Waste composition
- Water content
- Site specific factors such as subsurface conditions (for Subsurface Planar)
- Project location
- Regulatory and client requirements.

Equipment utilization efficiency, which is the percentage of available time the treatment process is operating (for either method), and waste loading (for ICV) are the most significant factors impacting costs. As with any process involving fixed or semi-fixed labor and equipment costs, the project costs are minimized when equipment utilization factors and waste loadings are maximized. For either case, lower unit treatment costs are realized from projects involving high waste volumes where increased efficiencies are possible.

GeoMelt requires materials that contain glass formers, such as soil, ash or sediment, to establish and propagate a melt. Non-soil wastes can be treated by ensuring there is a sufficient quantity of soil surrounding or mixed with the waste materials. This soil can be either clean or contaminated. The unit treatment costs are based on the aggregate volume of soil plus waste being treated. This is particularly important for the ICV process. The lowest unit treatment costs for ICV are achieved when the waste loading is highest.

There are many site-specific factors that can also impact the costs of operations, such as travel, per diem, and local costs of electricity. Also, subsurface conditions influence the approach taken when implementing the Subsurface Planar method.

Because of the types of variations noted above, the estimates are considered to be accurate within +30%, -10% for typical projects.

The cost analyses do not include remedial investigation (RI) and feasibility study (FS) type efforts. It is assumed that those activities have been done prior to selection of the technology. In addition, the cost estimates are based on an assumption that testing, development and demonstration costs have been handled separately, in advance of any remediation or waste treatment project. Such tests and demonstrations can be an important precursor for regulatory or other purposes and can be of value in optimizing the application engineering associated with a project. In such demonstration projects, the unit cost of waste treated is typically higher than that possible from routine commercial operations.

Cost Basis

The following cost analyses are based on full-scale operating experience with GeoMelt. The primary assumption made for these analyses are that the client would procure GeoMelt treatment services on a commercial basis from AMEC or its sub-licensee. Therefore, typical commercial enterprise related costs, like general and administrative overheads (G&A) and profit (fee) are included in the cost numbers. The cost estimates include the following standard cost accounting elements:

- Direct labor
- Direct materials
- Indirect materials
- Facilities and equipment
- Travel and per diem
- Subcontracted services.

The estimates include assumed labor overhead rates, general and administrative (G&A) overhead, cost of facilities capital, fee and royalties. The actual overhead rates would vary depending on the projected recovery of overheads through the duration of the project. The cost analysis assumes cost accumulation in the following categories as follows for the typical project:

- Capital equipment
- Equipment mobilization
- Site / waste preparation
- Sampling and analysis
- Melting operations
- Equipment demobilization
- Project data evaluation and reporting.

Subsurface Planar Cost Estimate

Table I summarizes the primary assumptions for the subsurface planar treatment of mixed waste contaminated soil using 1, 2 and 3 GeoMelt machines operating concurrently.

Table I. Assumptions Used in Cost Analysis for Subsurface Planar Treatment

Factor	Assumption
Remedial design	Done by others
Capital equipment	Vendor supplied (depreciation is included in overheads)
Mobilization	Distance from base: 1,000 miles
Site preparation	Infrastructure provided by others; vendor performance of process specific preparations
Sampling and analytical	\$3,000 per melt allowance, plus \$10,000 every 10th melt for more extensive off-gas sampling and analyses
Power consumption	675 kWh/ton
Average power level	2.0 MW
Melt size (average)	500 tons
Project size	1 machine - 20,000 tons 2 machines - 35,000 tons 3 machines - 50,000 tons
Depth of treatment	-5 to -30-ft below ground surface (25-ft depth range)
Number of hoods used	2 per machine
Downtime between melts	12 hours
Total cycle time	7.5 days per melt and hood move
Equipment utilization	24 hour per day 7-day per week basis. 290 days per year (80%)
Demobilization	Distance to base: 1,000 miles; secondary waste accepted by client
Site restoration	Done by others
Data evaluation & reporting	Incorporated in melting operations costs
Total staff employed	1 Machine - 15 2 Machines - 27.5 3 Machines - 41
Financial factors	Electricity: \$0.08/kWh plus \$2,000/mo demand charge Per diem: \$100/day (including lodging and food) Travel (air): \$800/round trip

The economies of scale noted at higher production rates are due primarily to projected reductions in labor requirements, labor overhead and G&A rates.

For example, the cost analysis assumes a 7-1/2 day cycle time between 500-ton melts. GeoMelt has been operated on this basis in past commercial projects. If for some reason (e.g., regulatory delay or other project complexities) the vendor is only able to produce a 500-ton melt every 9 days (compared to 7.5 days), then the operating costs would be about 16% higher than those indicated in the table.

Table II provides a breakdown of the projected costs for each of the three cases. The cases involve project sizes of 20,000, 35,000 and 50,000 tons of material to be treated using one, two and three GeoMelt machines respectively. The Table provides the projected costs for each of the primary work elements.

Table II. Components of Subsurface Planar Cost per Ton at Various Scales

Component	1 Machine ($/ton)	2 Machines ($/ton)	3 Machines ($/ton)
Mobilization	15.00	15.00	15.00
Site preparation	6.90	6.60	6.40
Site preconditioning	48.80	42.30	39.90
Melting operations	336.30	269.30	248.90
Hood moves	25.60	21.90	16.80
Sampling/Analytical	13.80	13.10	12.90
Demobilization	15.00	15.00	15.00
Total (rounded)	461	383	355

In-Container Vitrification Cost Estimate

Table III summarizes the primary assumptions for projected large-scale costs for the ICV treatment of stored wastes. For the purposes of the cost analysis, it is assumed the waste is 2,000 tons of mixed low-level radioactive waste contaminated soil and debris. For this project it is assumed that two containers are processed simultaneously. Thus, each batch consists of two separate melts, each involving the treatment of approximately 28.5 tons of waste.

Table III. Assumptions Used in Cost Analysis for In-Container Vitrification Project

Factor	Assumption
Capital equipment	Vendor supplied (depreciation is included in overheads)
Mobilization	Local project (location assumed to be DOE's Hanford Site)
Sampling and analytical	\$3,000 allowance per batch of 2 melts, plus \$10,000 every 10th batch for more extensive off-gas sampling and analyses
Specific power consumption	1,200 kWh/ton
Average power level	750 kW per melt, two melts treated simultaneously in each batch
Melt size (average)	28.5 tons (approx. 57 tons total per batch at 35 batches)
Project size	1 machine – 2,000 tons
Number of hoods used	Six
Downtime between batches	12 hours
Total cycle time	2.5 days per batch of 2 melts
Equipment utilization	24 hour per day 5-day per week basis
Demobilization	Local project; secondary waste accepted by client
Vitrified product	Disposed of on-site at DOE facility
Project data evaluation and reporting	Incorporated in melting operations costs
Total staff employed	1 Machine – 13 staff
Financial factors	Electricity: \$0.08/kWh plus \$2,000/mo demand charge Per diem: N/A – local project Travel (air): N/A – local project

The ICV project is assumed to occur at DOE's Hanford site, which represents a local project for AMEC's GeoMelt business unit. This assumption of a local project avoids costs such as travel and per diem for the operating staff. This approach provides for a more equitable cost comparison with alternative mixed waste treatment services, which are typically provided at the service provider's local fixed facility. Nevertheless, costs are included for establishment and disestablishment of the ICV plant on the Hanford site. Such costs are not required for mixed waste treatment service providers operating an established local facility.

Table IV provides a breakdown of the projected costs for each work element. The primary differences in work elements for the in-container method compared to the subsurface planar method involve the elimination of site preparation activities and the addition of vitrified product disposal.

Table IV. Components of In-Container Vitrification Cost

Component	Cost ($/ton)	Cost ($/lb)
Mobilization	91.15	0.05
Melting Operations	1235.73	0.62
Sampling/Analytical	122.17	0.06
Vitrified Product Disposal	64.00	0.03
Demobilization	71.73	0.04
Total (rounded)	1585	0.80

CONCLUSIONS

The costs for the subsurface planar method of $355-$461 per ton equate to 18-20 cents per pound. The cost for the in-container vitrification method of $1585 per ton equates to 80 cents per pound. These are extremely low treatment costs for mixed wastes compared to alternative technologies.

A 1996 study by the US Department of Energy determined that the unit costs for mixed waste treatment using thermal and non-thermal treatment processes typically ranged from around $8 per pound for most integrated thermal treatment systems to more than $14 per pound for certain integrated non-thermal treatment systems [11]. The DOE study did not include GeoMelt. This cost range equates to $16,000 to $28,000 per ton. The DOE study assumed ex situ treatment for a range of waste types, which is different from the GeoMelt cases described above. Nevertheless, the cost data indicate that the GeoMelt methods offer a significant cost advantage for the treatment of mixed wastes.

The subsurface planar method for mixed waste treatment is less costly than incineration of non-radioactive RCRA hazardous wastes based on incineration costs contained in an EPA report [12]. According to the EPA report, the average cost of off-site incineration for RCRA hazardous wastes is $529 per ton with the 25th percentile at $472 per ton, the median at $494 per ton and the 75th percentile at $587 per ton. The subsurface planar treatment costs for non-radioactive hazardous wastes are expected to be slightly lower than the projected costs of $355-$461 per ton cost for low-level mixed wastes.

The in-situ and on-site benefits of the subsurface planar method combined with its relatively low cost compared to other treatment methods indicates that GeoMelt is an ideal candidate for the treatment of mixed low-level wastes sites. In addition, because the subsurface planar method is also less costly than incineration for RCRA hazardous wastes, it should represent a lower cost alternative for the treatment of certain hazardous waste sites, particularly those sites with multiple contaminant types.

Compared with alternative technologies for the treatment of mixed wastes, the ICV method is relatively simple and robust. The ability of the ICV process to handle difficult-to-treat mixed wastes including debris combined with its relative low cost should make ICV an attractive treatment alternative for mixed wastes.

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