Two Novel Approaches

Lowering Waste Management Life-Cycle Costs through Onsite Volume Reduction of Class B and C Wastes

Targeted removal of class-driving isotopes and the Modular Vitrification System offer generators new choices for managing their waste and lowering their life-cycle costs for any disposition path in a disposal-path uncertain world.

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With the uncertainty of Class B and C disposal options and pricing following the July 2008 loss of access to the Barnwell Low-Level Waste Disposal Facility, the sole national Class A, B, and C LLW disposal site, 90 percent of the nation's LLW generators are seeking new means to cost-effectively disposition these wastes without prejudicing future disposal options. If nuclear power is to fully take its critically important place as a safe, secure, and clean nongreenhouse-gas source of energy, it must first resolve the problem of uncertain Class B/C waste disposal. Here we review existing disposition options for the approximately 15 000 cubic feet of Class B and C wet waste (e.g., ion exchange resins, filters) generated annually[1] and present two novel approaches for generators to expand their waste management toolbox.

Prior to the closing of Barnwell, there was active competition for Class B and C wastes between direct disposal and offsite facilities selling waste volume-reduction services at a discount off the disposal site's gate price. With the closing of Barnwell to out-of-Atlantic Compact generators, utilities were faced with storing the newly orphaned Class B/C waste in high-integrity containers (HICs). (The Barnwell LLW disposal site is located in the Atlantic Compact, which comprises South Carolina, New Jersey, and Connecticut. See Fig. 1.) But storing waste in HICs entails using existing or new storage space, actively monitoring that space, tracking activity and classification, resolving the increased fire burden from polyethylene HICs and organic media, and incurring an accrual charge for future transportation and disposal—collectively, a high "mortgage" cost for Class B and C wastes.

Following the closure of Barnwell, generators without disposal access have been exploring a set of evolving Class B/C waste disposition options, including (a) onsite storage; (b) altering plant practice to mitigate Class B/C waste generation; (c) sending all media- and filter-based Class B/C waste to an offsite processor for blending with Class A wastes to create a "high-activity" Class A waste for disposal at the Clive, Utah, Class A LLW disposal facility; and (d) shipping Class B/C wastes to an offsite processor for volume reduction, transfer of title and control, and indefinite offsite storage under a trust fund. Each of these options comes with a life-cycle cost based on incurred and accrued handling, packaging, storing, shipping, disposal costs, and other risks to the generator. We evaluate these options against two novel onsite Class B/C disposition approaches:

- *Targeted Removal of Class-Driving Isotopes:* A processing logic based on utilizing extremely high performing inorganic ion specific media (ISM) to target and remove specific isotopes that drive waste to Class B and C at the point of creation. The resulting volume reduction mitigates HIC purchases, excessive storage, storage facility fire burden, and the need for shipments to offsite processors with take-title and loss-of-control risks.
- *Modular Vitrification System:* The MVS® employs a patented first-principles single-use melter internally integral to the waste container that achieves high waste volume reduction. By creating a vitrified waste form, the MVS immobilizes the waste into a stable form that far exceeds the requirements of the *Code of Federal Regulations* (CFR), Title 10, Part 61, and the stabilization achieved by HICs. The waste form is accepted at LLW disposal sites and is rated "best demonstrated available technology" by the U.S. Environmental Protection Agency.[2] In addition, the MVS eliminates the need for HICs, additional storage, and increases in the storage facility fire burden.

These Kurion technologies result in superior reductions in Class B/C waste volumes while saving generators significant life-cycle costs in the process. Also, when the two methods are used together on certain waste streams, the volume reduction enables the option for assured disposal, an industry first. Both offer generators new tools for managing their waste and lowering their life-cycle costs for any disposition path in a disposal-path uncertain world, regardless of whether new Class B/C LLW disposal access becomes available in the future. By mitigating or eliminating the purchase of HICs, excessive storage, increases in facility fire burden, shipments to offsite processors, and associated take-title and loss-of-control risks, these new disposition options yield the lowest life-cycle cost while providing flexibility for on- or offsite storage as well as future disposal options.

Disposal Sites and Volumes

The United States principally uses a two-tier system, LLW and high-level waste, to characterize its wastes. The LLW category generally encompasses the low- and intermediate-level waste categories typically found in other countries. With the exception of spent fuel, federal law precludes disposal of commercial radioactive wastes at U.S. Department of Energy sites, which is unfortunate given the significant LLW disposal options enjoyed by the DOE.

The Low-Level Radioactive Waste Policy Act of 1980 and the Low-Level Radioactive Waste Policy Amendments Act of 1985 provide relief from interstate commerce laws by allowing states to group together and form "compacts" to control access and charge tariffs for waste generators located in states outside the compact that desire access to an LLW disposal site located within the compact. (While the U.S. government regulates interstate commerce, the individual states are responsible for laws governing commerce within their borders. Part of the laws governing interstate commerce prohibits a state from limiting or charging tariffs for access to its markets by businesses located in "foreign" states.) Figure 1 shows the current status of the U.S. LLW compacts.

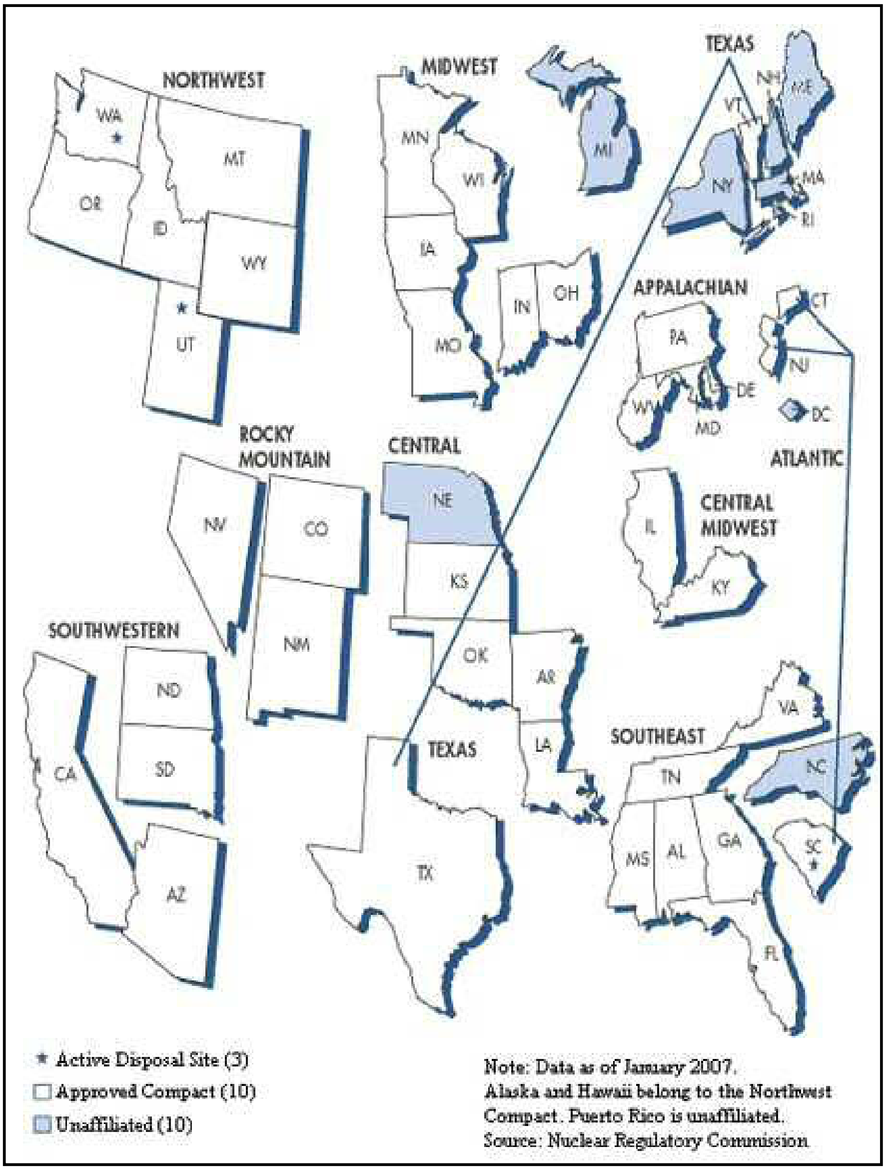

Fig. 1. U.S. LLW compacts.

Title 10, CFR 61 classifies LLW into four classes—Class A, B, C, and greater-than-Class C (GTCC)—based on the concentration of specific short- and long-lived radionuclides, with GTCC having the highest radionuclide concentrations. The maximum specific activity for these isotopes for each class is provided in Table 2 of 10 CFR 61, and wastes containing multiple nuclides have their classification determined by the sum of fractions rule. The LLRW Policy Amendments Act of 1985 assigned the federal government responsibility for the disposal of GTCC LLW that results from activities licensed by the U.S. Nuclear Regulatory Commission and Agreement States.

Disposal of Class B and C wastes pursuant to the requirements of 10 CFR 61 requires meeting 300-year and 500-year environmental isolation criteria, respectively. Using the disposal database of the Manifest Information Management System[3], the Electric Power Research Institute (EPRI) evaluated and reported on U.S. commercial LLW generation by class and waste type. Excluding the small amount of activated metals, the EPRI found that U.S. nuclear plants generate approximately 1 million cubic feet of LLW a year, with about 65 percent of the activity concentrated in only 15 000 ft^3 of Class B and C resins and filters (80/20 by volume). With Class B/C LLW typically packaged in polyethylene HICs for stability, this equates to about 156 HICs annually, or 1.5 HICs per reactor. (The typical HIC for Class B/C waste is designed for shipment in a CNS 8-120B shipping cask.)

Table I. Key Class Driving Isotope Concentration for Average 1000-MWe Reactors

Parameter	BWR	PWR	Units
Volume	214	109	Cubic feet
Ni-63	4.03	35.75	Curies
Sr-90	0.15	0.09	Curies
Cs-137	11.05	18.85	Curies
Average Class	B	B	10 CFR 61
10 CFR 61 Table 2	0.051	0.305	Sum of fractions

Table I provides typical waste stream profiles for the key classification driving isotopes generated at U.S. reactors. It is based on data provided in a 2009 EPRI presentation on total LLW generated by reactor type[4] and allocated to Class B/C resins and filters using the relative volumes and activities provided by the EPRI study in Ref. 1.

Present Class B and C Waste Disposition Options

In a post-Barnwell world, generators without Class B/C disposal access are exploring the following evolving choices for the disposition of Class B/C wastes:

- Store Class B/C onsite. Storing waste onsite entails using existing or new storage space, active monitoring of that space by the health physics organization, tracking activity and classification, resolving the fire burden increase from the polyethylene HICs and organic media, and incurring an accrual charge for future disposal. In addition, multi-year storage degrades the HIC dewatering internals, creating a potentially expensive resolution challenge if disposal access becomes available. The accrual rate for disposal cost is based on the generator's forecast for new disposal access. With the June 30, 2008, closing gate price for the Barnwell disposal site of $3146/ft^3$ for processed and unprocessed resins and filters, Class B or C, serving as a floor,[5] generators currently use $3500 to $4500/ft^3$ as the disposal accrual basis for Class B/C wastes.[6] The accrual charge is generally lumped into a single rate per cubic foot based on the mortgage cost for the containers, shipment, and monitored storage plus the anticipated disposal rate. This lump sum accrual charge then forms the life-cycle baseline for evaluating onsite waste storage versus alternative strategies. In a recent paper, the EPRI concluded that onsite storage represents a capital investment and liability for future disposal and regulatory risk,[7] reinforcing the desirability of mitigating onsite storage and identifying assured disposal paths.
- Alter plant practice to mitigate Class B/C creation. Accomplished by either "short loading" demineralization vessels, improving waste segregation, or replacing media more frequently to keep it within a Class A classification. Traditionally, generators simply filled demineralization vessels to the capacity of the vessel. Short-loading refers to loading the demineralization vessel only to the point required to achieve the processing objectives. The practice of replacing media more frequently has the consequence of increasing Class A waste generation, associated media/filter purchases, handling, shipments, and disposal charges at the nationally available Clive, Utah, Class A LLW disposal site (the scenario evaluated later in the life-cycle analysis of Table IV).
- Don't avoid creating Class B/C wastes; continue operations as normal. This alternative to direct disposal entails shipping Class B and C wastes to an offsite processor for volume reduction, transfer of title and control, and indefinite offsite storage under a trust fund until a new Class B/C disposal site becomes available. Given that generators cannot fully give up responsibility for wastes, they remain at risk of some form of reach-back "Superfund" action if the commercial entity responsible for storage fails, if policies of the state hosting the storage site change, or if no new disposal site opens.
- "Down-blend" Class B/C. This approach, pending regulatory approval (see the following), involves sending all media- and filter-based LLW to an offsite processor for mixing and blending the Class B/C waste streams with Class A wastes to create a "high-activity" Class A waste blend for disposal at the Clive disposal site. Although this approach is likely acceptable under strict review of the disposal classification rules of 10 CFR 61, it runs afoul of prior NRC positions since 1981 against comingling higher and lower activity wastes to achieve a lower classification and changes decades of plant culture and stakeholder accepted practices of (a) volume reduction for a given waste class and (b) not declaring the waste for shipment under 10 CFR 61 disposal classification. Finally, and more troubling for the industry, is the potential political backlash by the Utah legislature if, through a "dilution" process, the Clive site owner were allowed to dispose of the same number of curies it had committed to not bring into the state. When it acquired the Clive Class A LLW disposal facility in 2005, EnergySolutions assured Utah that it would abandon plans to expand its site's license to include Class B/C wastes. Should EnergySolutions attempt to dispose of materially the same number of curies it would have achieved under a Class B/C license but through the "backdoor" process of down-blending, they risk a strong backlash by the Utah legislature, including restricting access to the Clive disposal site and jeopardizing the safe annual disposal of 1 million ft^3 of waste.
- "Risk-informed" adjustments to disposal requirements. Industry has generally favored a review of the existing disposal regulations and NRC Branch Technical Position using a risk-informed approach. The hope is that this would allow some of the waste, currently classified as Class B/C, to be disposed of at the Clive site as Class A[1]. As reported by the NRC staff at the June 2010 EPRI International LLW Conference, the commission is being asked to address several LLW disposition rule changes covering down-blending, classification requirements, and depleted uranium. The staff reported that the decision path has yet to be determined (single or combined rulings) and that rule changes could take up to five years because of the cycle of public hearings, feedback, etc.

Even if the afore-mentioned options are fully utilized, estimates show that up to 50 percent of Class B/C wet waste still remain unresolved.[7,8] As a result, the industry is hoping for the creation of a new LLW disposal site that could accept Class B and C wastes. After 15 years of effort, Waste Control Specialists (WCS) appears to be on a successful path to achieving approval from the Texas Commission to open a new LLW disposal site for the Texas Compact in 2011. Since the inception of the LLRW Policy Amendments Act of 1985, the United States has "invested" approximately $1 billion in failed attempts to site new LLW disposal facilities. As a result, Texas and WCS deserve great praise for the political and technical leadership they have demonstrated to our nation in developing this new and environmentally responsible LLW disposal capacity. Because the Texas Compact[9] is limited to generators in Texas and Vermont, the cost to design, license, construct, and operate the WCS facility must be allocated over only four reactors in Texas and one in Vermont. As a result, in late 2009 WCS requested a license amendment to allow importation of LLW from outside the Texas Compact, justified by the creation of a disposal option economically attractive to the Texas Compact generators without which, WCS testified, the viability of the LLW disposal site is in question.[10] The June 2010 WCS compact LLW Disposal Rate Application Package documents a $5872/ft^3$ disposal rate request for out-of-compact B/C waste,[14], significantly higher than the closing Barnwell gate rate and the

Illustration Showing Same Isotope Removal Achieved Using Less High Kd Media	Higher Kd Media Results in Proportionally Reduced Waste Volumes

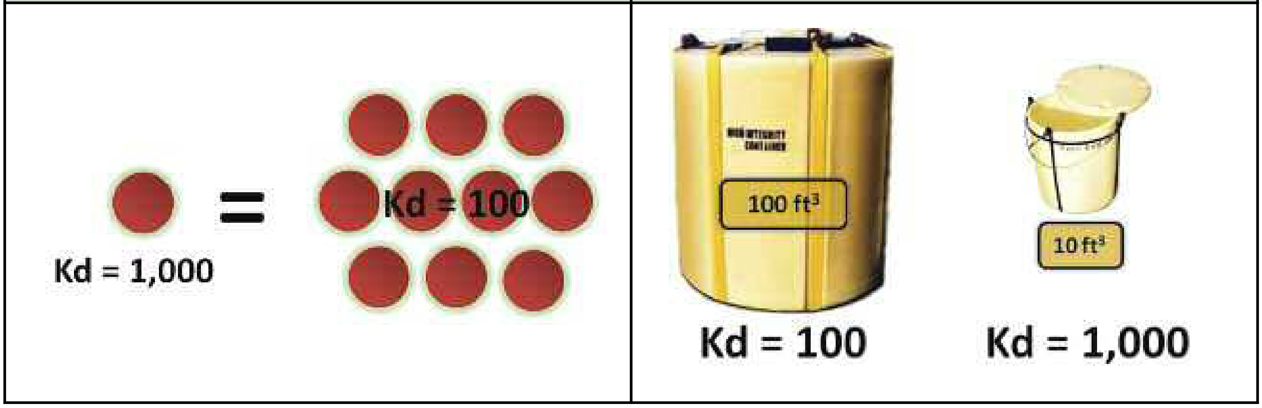

Fig. 2. Distribution coefficients equate media dose to achieve isotope extraction equivalence.

$3500/ft^3 to 4500/ft^3 range used by the industry according to EPRI.[6]

First Novel Approach: Targeted Removal of Class-Driving Isotopes

The EPRI reported that Class B is largely driven by Cs-137, Ni-63, and Sr-90, listed in descending order of significance of classification contribution, and that "selective cesium removal from liquid waste streams would *significantly* reduce Class B waste volumes."[11] Kurion has expanded on this logic by developing extremely high performing inorganic ISM to target and remove specific isotopes that drive Class B and C waste volumes at the point of creation.[12]

The concept of distribution coefficients is used to distinguish performance differences between competing media. The distribution coefficient is defined as Kd = S/C mass ratio/concentration (mg/g/mg/ml =) ml/g, where S = mass (or activity) of contaminant "sorbed" at equilibrium per mass of sorbent and C = equilibrium concentration (or activity) of soluble contaminant in aqueous phase. Stated differently, the distribution coefficient allows comparisons of the amount of media dose to achieve the same isotope extraction result. Figure 2 provides a graphical representation of using two media having different distribution coefficients by a factor of 10:1 to achieve the same level of isotope removal. Inverting this concept, the figure shows that an effective volume reduction of 10:1 has also occurred, because only one-tenth of the amount of media of the higher distribution coefficient is required to achieve the result of the lower performing media. Given that it is the amount of media, not the isotopes, that drives resin volumes, one can compare potential volume reductions of different media by their distribution coefficients. The features and benefits of targeted removal of class-driving isotopes are listed in Table II.

Table II. Features and Benefits of Targeted Removal of Class-Driving Isotopes

Features	Benefits
Media Delivery	• Bead media – works with existing plant demineralization systems. • Powder – Micron-size product, a pure sorbent w/huge surface area that can be used as Powdex-like precoat or allowing for a seeding process in a batch reactor mode for increased performance
Safety	• Eliminates off-gassing concerns from bug/bacteria on organic media • Eliminates media fire burden hazard during onsite storage
Volume reduction	• Minimizes B/C creation during at-plant waste processing by segregation of B/C classification drivers using significantly less media than currently possible • Yields comparable to or improved volume reduction over streamwide averaging/down-blending or thermal treatment
10 CFR 61 Compliance	• Works within present or likely future NRC Branch Technical Position revisions • Dramatically reduced B/C safety-storage-shipping-liner-disposal costs • Classification flexibility with option in selected cases to concentrate waste to GTCC for disposal assurance
Economics	• Lowest life-cycle cost • Increased waste disposition competition

The general concept of using selective media to reduce Class B/C volumes has been around for some years. However, the advent of extremely high performing media at pricing that justifies its use has historically not been available. At the June 2010 EPRI International Low-Level Waste Conference, Kurion introduced results of its program to develop extraordinarily high distribution coefficient ISM targeted to key isotopes.[12] This media will be commercially available in 2011 and sold at competitive prices to ensure attractive life-cycle cost comparisons. While the referenced paper offers details of the ISM, a high-level summary comparison is provided in Fig. 3, which shows the ISM distribution coefficients as tens of times to 1000 times higher than existing industry media.

A key aspect of the ISM is that they are inorganic as compared with conventional organic media. This has the advantage of eliminating concern about the media as a fire hazard burden during storage, eliminating NOx and SOx emissions during thermal treatment, and eliminating off-gassing from "bug"/bacteria growth during storage. Although far more robust than organic media, the media experiences volume reduction during thermal treatment as the structure collapses. Because of strong molecular bonds, however, isotopes remain captured during thermal treatment, eliminating concerns over volatization of isotopes such as cesium.

The company's development program includes the ability to manufacture its media using patent pending sorbent-impregnated porous glass microspheres. As a result, during vitrification the media self-supplies the glass frit required for vitrification, thereby avoiding glass former additions, allowing a volume reduction unavailable to other vitrification systems.

Assuming the high distribution coefficient media were applied to an average waste stream, such as shown in Table I, and a volume reduction of 10:1 was achieved, the corresponding 10:1 specific activity increase would drive all pressurized water reactor and boiling water reactor wastes to Class C waste. However, because Table I presents an average over all plants and waste streams, specific waste streams would have to be monitored if the generator's goal is to exceed, or not exceed, Class C.

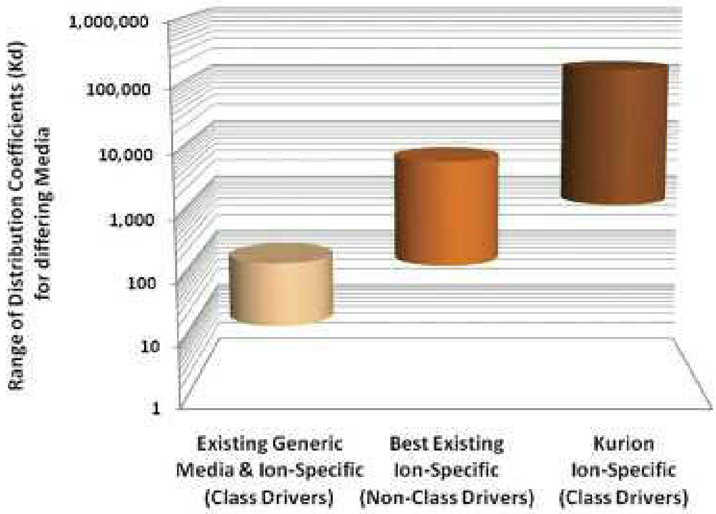

Fig. 3. Distribution coefficient comparison.

The resulting volume reduction mitigates HIC purchases, excessive storage, and storage facility fire burden and eliminates concerns about off-gas from bug/bacteria growth on media and the need for shipments to offsite processors with take-title and loss-of-control risks. As a result, this processing strategy results in the lowest life-cycle costs for any disposition path, storage or disposal (see Table IV).

Second Novel Approach: Modular Vitrification System

As an enhancement to targeted removal of class-driving isotopes or as an onsite volume reduction of existing ion exchange media, vitrification can be used to volume reduce the media and improve its waste form to eliminate the need for poly HICs. Through vitrification, waste is immobilized into a stable form that far exceeds the requirements of 10 CFR 61 LLW or the stabilization achieved by HICs. Unlike steam-reformed waste or HICs, a vitrified waste form meets the overburden, stabilization, and monolith requirements of HLW, making the MVS vitrified waste form uniquely suitable for disposal as Class B/C or GTCC. Vitrification is the preferred disposition choice because it offers environmental protection beyond that which can be provided by engineered barriers and/or containers.

Kurion has developed an MVS that is simple enough to allow generators to safely perform this process onsite. Granted eight patents, the MVS employs a mechanically passive, first-principles, single-use melter internally integral to the customer's waste container and achieves high volume reduction (see Fig. 4). The self-contained system utilizes nonintrusive inductive energy as its heat source to avoid electrodes, thermocouples, and probes normally associated with vitrification processes and that create secondary wastes along with maintenance, safety, and cost concerns. In addition, because the MVS does not rely on high temperatures to ensure glass conductivity and heating as required of joule-heated melters, it is uniquely capable of utilizing low-temperature glass formations to stay below the volatization temperatures of off-gassing isotopes such as cesium.

As illustrated in Fig. 4, the MVS utilizes a thin-walled crucible internal to the waste container that acts as a susceptor to be preferentially excited and heated by induction energy. The segmented induction coils are switched on or off as appropriate to follow the shallow melt zone as it travels upward during canister filling. A gravity feed system introduces the waste/glass mixture, or glass microspheres in the case of the Kurion version. The combination of a gravity feed system and segmented coils ensures a mechanically passive waste processing system.

A shallow melt zone is used to avoid convective currents that could increase the energy of the melt pool by ejecting isotopes that easily volatize. This quiescent melt pool approach is in sharp contrast to the long soak time or high-energy stirring (e.g., bubblers) characteristic of box-shaped joule-heated melters to en-

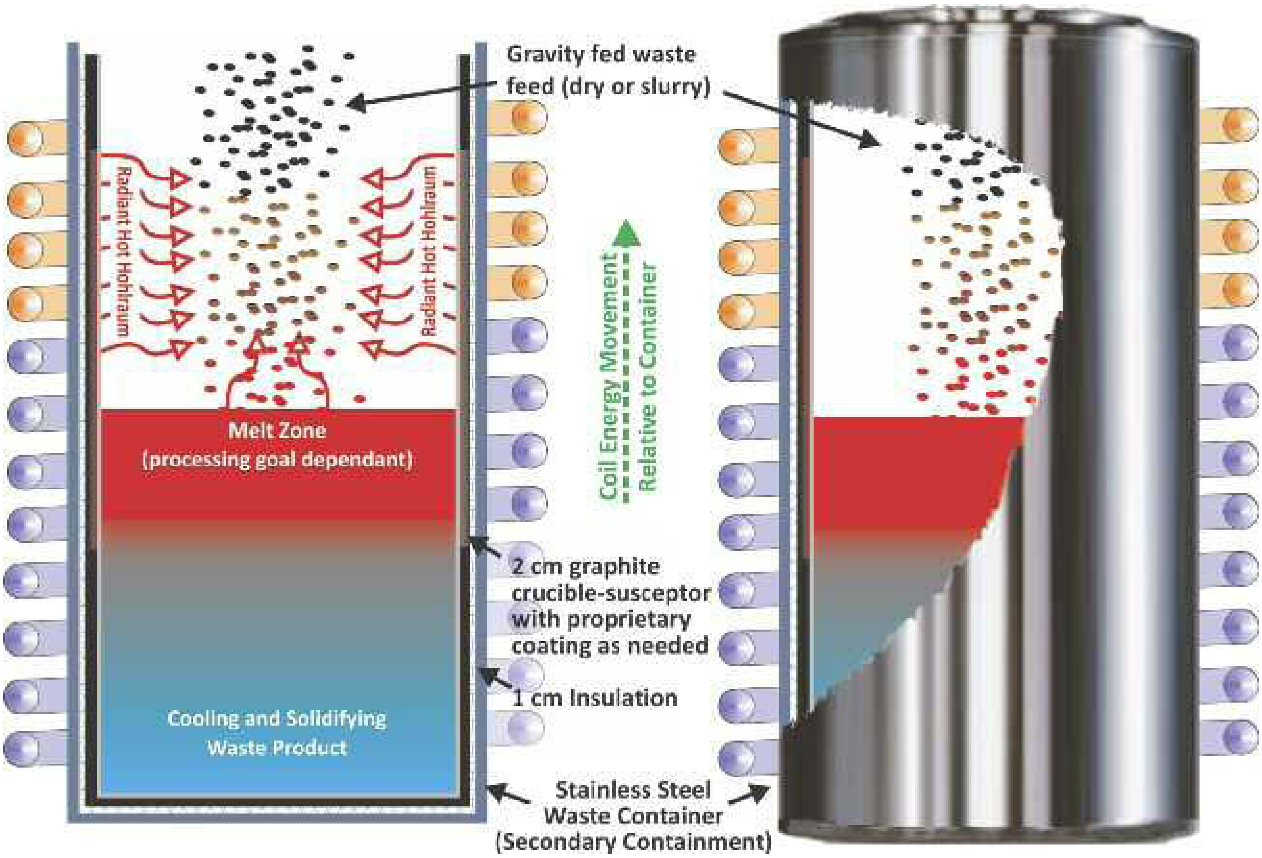

Fig. 4. MVS schematic diagram and cutaway of stainless steel waste canister.

sure homogeneous mixing, which results in increased off-gassing.

The MVS eliminates the concerns associated with traditional joule-heated melters, because all melting and glass formation takes place inside the mechanically passive, single-use final waste container. It also eliminates the concerns with in-container joule-heated vitrification systems with complex refractory designs integral to the waste canister that experience melt-through and leakage of volatile isotopes through the refractory. Furthermore, the modular, robust, and flexible nature of the Kurion batch approach uniquely reduces the pretreatment requirement by allowing the operator to modify the glass formation and/or process to conform to the requirements of the incoming waste stream.

Aside from a small footprint and negligible off-gas, the MVS has the ability to keep the stainless steel waste canister relatively cool while processing. Kurion's unique proprietary process keeps the waste canister exterior more than 500°C cooler than does the interior process, plus it doubles as a secondary containment.

The use of the MVS to further reduce volumes enables the option of assured disposal by driving Class B/C waste to GTCC, which is consistent with industry practice, stakeholder support, and NRC guidance of volume reduction and disposal whenever practical. Under Sec. 3(b)(1)(D) of the LLRW Policy Amendments Act of 1985, the DOE is responsible for the disposal of GTCC LLW that results from NRC and Agreement State–licensed activities. Reactors already routinely generate GTCC waste in the form of activated metals coming from reactor components and occasional filters and media (e.g., spent fuel pool filtration systems and SWARF from cutting operations). Currently, the DOE estimates that the stored and projected volume and activity of GTCC LLW and DOE GTCC-like waste is approximately 5600 cubic meters (around 200 000 ft^3) and 140 million curies.[13] Using the data in Table I, we find a volume reduction of approximately 150:1 is required to convert the entire industry's 15 000 ft^3 of annual Class B/C waste generation to GTCC. Applied over the approximately 30 years of remaining fleet life, this represents an increase to the present DOE planned GTCC inventory by 1.5 percent. This demonstrates that there is insufficient Class B/C waste under any processing scenario to have a consequential impact on the DOE planning for GTCC disposal.

Kurion will be developing design concepts for nuclear plant MVS systems for commercial launch end-2011. Basic parameters include skid-mounted equipment, the ability to hang shielding, and remote and automated operability. Because the MVS is a scalable technology, the waste canister can be of almost any size to fit customer needs. And because all contamination is retained inside the melt zone, the exterior of the waste canister remains clean. Stainless steel is preferred as the waste canister material of construction to present a durable and clean handling interface. Based on anticipated volume reductions, Kurion is considering small stainless steel waste canisters that would have approximate dimensions of 74 inches tall by 14 in. outer diameter (see Fig. 4). This size canister can accept approximately two years' worth of vitrified media for waste from a typical reactor, and 10 can be shipped in a single CNS 8-120B cask shipment. Because the MVS can be started and stopped, generators would be able to top off unfilled canisters.

Table III. Features and Benefits of the Modular Vitrification System	
Features	**Benefits**
Safety	• The MVS is a mechanically passive system • All contamination is internal to the waste canister • Negligible off-gas due to its unique ability to use low-temperature glass formulations that complement its low-energy melt pool • Eliminates off-gassing concerns from bug/bacteria on organic media • Eliminates fire burden hazard during onsite storage
Volume reduction	• Minimizes B/C creation during at-plant waste processing by 5:1 or higher • Smallest Class B/C volume of any alternative
10 CFR 61 Compliance	• Works within present or future NRC BTP revisions • Dramatically reduced B/C safety-storage-shipping-liner-disposal costs • Classification flexibility with option to concentrate waste to GTCC for disposal assurance
Economics	• Smallest possible disposal volume, shipping and disposal costs • Increased waste disposition competition

By processing inside a stainless steel canister and achieving 5:1 and higher volume reductions (waste stream dependent), the MVS eliminates the purchase of HICs, additional storage requirements, facility fire burden increases, shipments to offsite processors and associated take-title and loss-of-control risks and is the sole option that allows assured disposal via GTCC. In combination with the Kurion ISM, generators could potentially fit the balance of plant life Class B/C media-based wastes in a single shielded onsite storage container and store until disposal, avoiding the cost of additional storage and monitoring. As a result of these benefits, this processing strategy results in reduced life-cycle costs. The features and benefits of the MVS are shown in Table III.

Impact on Disposal

Utility volume-reduction efforts benefit the LLW disposal sites by extending their useful life. For example, if the WCS LLW disposal site is opened and ultimately approved to import out-of-compact waste, WCS will be faced with larger volumes than the site was designed for over its life. This implies reopening the site license for amendment to additional disposal trench volume. Consequently, it would open the door for intervenors and the kind of politicized scrutiny that in part caused the closure of the Barnwell site over unfair claims of being the nation's radioactive waste dumping ground. A volume-reduced vitrified waste form would allow WCS to better utilize their existing disposal trench design and avoid reopening the licensing process. In addition, by accepting Class B/C waste stabilized at a standard normally reserved for HLW, WCS and the industry take a proactive step to mitigate intervenor concerns over waste immobilization and environmental isolation.

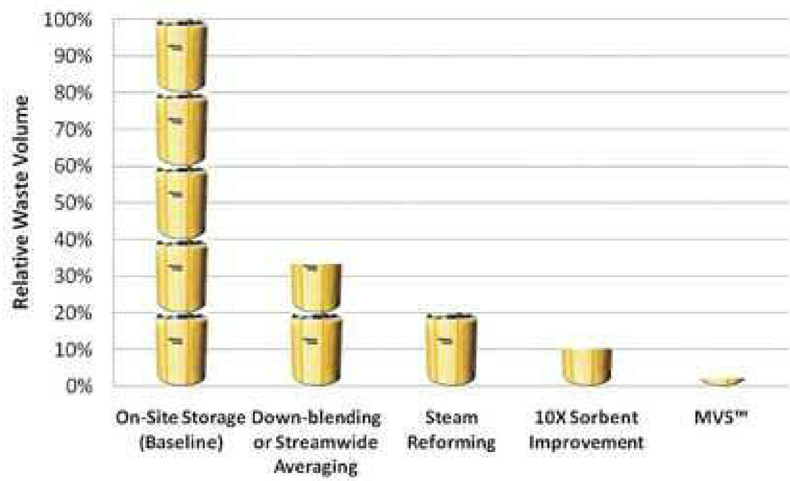

Fig. 5. Relative storage/disposal volumes.

Life-Cycle Cost Analysis

To evaluate and rank the various Class B/C waste disposition options, generators should perform a life-cycle cost analysis based on their individual situations. For the interim, Table IV shows an example of such analysis based on industry average waste streams listed in Table I. The life-cycle cost analysis identifies the costs associated with each processing step to determine the incremental disposition cost per cubic foot of media. The column on the far right in Table IV ranks the competing Class B/C waste disposition approaches by normalizing the cost relative to the baseline media volume.

In compiling the life-cycle analysis in Table IV, we made a number of assumptions, including the relative costs of competing media, shipments, and processes. Because the vendors who offer services will benchmark against the baseline costs and competitor costs as market forces, our analysis took this same approach for estimating their processing charges. Additionally, because generators currently use \$3500 to \$4500/ft^3 as the disposal accrual basis for Class B/C wastes,[6] this analysis took a conservative approach and used \$3500/ft^3. Figure 5 illustrates the rela-

Table IV. Life-Cycle Cost Analysis of Competing Class B/C Waste Disposition Approaches

Class B/C Waste Strategy															
Class B/C Waste Strategy	Media Metrics		Waste Processing							Storage & Disposal					Summary
	Pre-Processing Volume	Media Costs	No. Type B shipments to Off-site processor (reusable liner)	Type B Shipping Costs to Off-site Processor	Waste Processing Cost as % of Class B/C Disposal	Volume Reduction	Post-Processing Volume	Waste Processing Cost	Waste Class	Disposal Container Size	No. Shipments to Disposal**	Waste Container & Shipping Costs to Disposal Site	Disposal Cost	Storage Costs (assumed 10% of Disposal)	Disposal Accrual Normalized Against Baseline Media Volume
On-Site Storage (Baseline)	1 cu-ft	$500	n/a	n/a	n/a	1.0:1	1 cu-ft	n/a	Class B/C	120 cu-ft	0.010	$343	$4375	$438	**$5655/cu-ft**
Direct Disposal	1 cu-ft	$500	n/a	n/a	n/a	1.0:1	1 cu-ft	n/a	Class B/C	120 cu-ft	0.010	$343	$4375	n/a	**$5220/cu-ft**
Adjust plant practice to mitigate Class B/C*	5 cu-ft	$2500	n/a	n/a	n/a	1.0:1	5 cu-ft	n/a	Class A	210 cu-ft	0.030	$982	$2188	n/a	**$5670/cu-ft**
Off-Site Processing & Storage	1 cu-ft	$500	0.01	$125	95%	5.0:1	0.2 cu-ft	$3325	Class B/C	120 cu-ft	0.002	n/a In process fee	n/a In process fee	n/a In process fee	**$3950/cu-ft**
Off-Site Down-Blending* & Disposal	1 cu-ft	$500	0.01	$125	80%	0.2:1	5 cu-ft	$2800	Class A	210 cu-ft	0.006	$111	$438	n/a	**$3975/cu-ft**
Targeted Removal of Class-Driving Isotopes	0.1 cu-ft	$1000	n/a	n/a	n/a	1.0:1	0.1 cu-ft	n/a	BWR Class B PWR Class C	120 cu-ft	0.001	$34	$438	$44	**$1515/cu-ft**
Targeted Removal + On-Site Vitrification	0.1 cu-ft	$1000	n/a	n/a	n/a	6.0:1	0.02 cu-ft	$1550	BWR Class C PWR GTCC	120 cu-ft	0.0003	$10	$133	$13	**$2705/cu-ft**
Selectively Decon Organic + Targeted Removal + On-Site Vitrification	1.0 cu-ft	$500	n/a	n/a	n/a	60.0:1	0.02 cu-ft	$2550	BWR Class C PWR GTCC	120 cu-ft	0.0003	$10	$133	$13	**$3205/cu-ft**

Notes/Assumptions: $3500/cu-ft = Class B/C waste disposal price.
$350/cu-ft = Class A waste disposal cost.
$500/cu-ft = Cost of ion specific media.
$15 000 = cost per disposable 120 High Integrity Container.
$18 000 = cost per Type B shipment for Class B/C wastes. Type A shipments to Clive for Class A waste at are approximately the same cost as Type B shipments to a longer distance.
80% = waste container net waste volume efficiency (=waste volume/disposal volume).
10 = number of MVS cannisters per CNS 8-120B shipment. HICS are one per CNS 8-120B shipment.
* The scenarios "Adjustment to plant practice" (replace media more often) and "off-site down blending" are both assumed to apply similar levels of Class A dilution to mitigate Class B/C.
** Original volume used to determine the number of disposal shipments for the down blending case.
The analysis ignores HIC integrity risks during storage to methane production from bacterial action in moist organic media.
The analysis ignores storage risks changes from fire hazards caused by organic media and poly HICs.
The analysis ignores dose-to-worker costs regarding differences in materials handling, monitoring, and shipments.

tive disposal volumes of the alternative disposition paths. Important costs missing in the analysis in Table IV are the handling costs and dose-to-worker costs, which would have a tendency to drive up the relative costs of disposition processes that involve extra waste handling.

The Kurion ISM and MVS are conservatively shown at their low end of volume reduction, which when combined result in a volume reduction of 60:1. However, actual combined volume reductions of greater than 100:1 are possible, allowing the generator the option to concentrate waste to the high end of Class C or to GTCC if disposal surety is the target.

Three cases are examined for the Kurion technologies: (a) ISM only, wherein this media is substituted for lower performing media; (b) ISM and MVS, wherein ISM is substituted for lowering performing medai and then vitrified for further volume reduction; and (c) organic media followed by an ISM/MSV combination. The third option is included as a comparison of a Kurion proprietary approach to significantly volume reduce the Class B/C liability created by organic media used in primary loop coolant purification systems—the dominant source of Class B/C volumes.

The three Kurion technologies yield the lowest life-cycle cost regardless whether the generator must storage or has disposal availability (see Table IV). The two options where ISM and MVS are used in combination provide the unique option and ability for an assured disposal pathway, an approach that enhances the industry's argument for new, clean, safe, secure reactors. The third (and proprietary) Kurion option also allows the generator the novel ability to achieve very high reduction of Class B/C liabilities from resins that are either in storage or can't currently be replaced by Kurion's ISM.

In Class A-only disposal scenarios, there are practical limitations on the amount of Class B and C waste volume reduction that is achievable by altering plant radwaste practice, offsite down-blending, or "risk-informed" changes to 10 CFR 61.[1,7,8] In the end, these processing approaches cannot be used for a significant percentage of Class B/C wastes, which makes for excellent candidates for the Kurion technologies. Therefore, generators are best served by developing their own life-cycle cost analyses to evaluate various combinations of their Class B/C waste disposition options.

The Path to Disposal Certainty

The Kurion technologies result in high volume reductions of Class B and C wastes. Both the technologies offer customers new choices for managing their waste and lowering their life-cycle costs for existing and future disposition paths (storage or disposal availability). If disposal certainty is the target, the novel ability of ISM and MVS to achieve combined volume reductions in excess of 50:1 offers generators the unique option of driving selected waste streams to GTCC. Lastly, the technologies are consistent with decades of industry practice, stakeholder support, and NRC guidance of volume reduction and disposal whenever practical.

Given that the story has yet to be fully written regarding the opening of new LLW disposal at WCS, their ability to import waste, and the impact of the associated jump in Class B/C disposal rates on generator waste disposition accruals, generators should seek out disposition solutions that are storage- and disposal-friendly with the lowest life-cycle cost analysis. Along with avoiding the creation of Class B/C waste, using the new Kurion technologies can help generators greatly reduce their life-cycle costs.

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