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EFFECTS OF WASTE CONTENT OF GLASS WASTE FORMS ON SAVANNAH RIVER HIGH-LEVEL WASTE DISPOSAL COSTS

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ABSTRACT

Effects of the waste content of glass waste forms on Savannah River high-level waste disposal costs are evaluated by their impact on the number of waste canisters produced. Changes in waste content affect onsite Defense Waste Processing Facility (DWPF) costs as well as offsite shipping and repository emplacement charges. A nominal 1% increase over the 28 wt % waste loading of DWPF glass would reduce disposal costs by about $50 million for Savannah River wastes generated to the year 2000.

Waste form modifications under current study include adjustments of glass frit content to compensate for added salt decontamination residues and increased sludge loadings in the DWPF glass. Projected cost reductions demonstrate significant incentives for continued optimization of the glass waste loadings.

I. INTRODUCTION

In the Savannah River plan for high-level waste disposal, aqueous radioactive wastes are processed into solid form for final disposal.[1,2] Sludge components of the waste and radionuclides separated from waste salts[3] are converted to glass by melting in the Defense Waste Processing Facility (DWPF),[2,4] and the decontaminated salt solutions are fixed in concrete for onsite burial.[5] After a period of interim storage, the waste glass contained in stainless steel canisters will be shipped to a federal geologic repository for final disposal.[6]

Optimization of the glass waste forms to be produced in the DWPF is being supported by economic evaluations of the impact of the forms on waste disposal costs. Glass compositions are specified for acceptable melt processing and durability characteristics, with economic effects tracked by the number of waste canisters produced. This paper presents an evaluation of effects of variations in waste content of the glass waste forms on the overall cost of disposal, including offsite shipment and repository emplacement, of the Savannah River high-level wastes. The status of recent investigations undertaken to optimize compositions of the sludge-salt glasses are outlined.

II. BACKGROUND

High-level radioactive wastes at the Savannah River Plant, now contained as aqueous sludges and salts in large underground tanks, will be processed to solid form for final disposal.[1] The principal activities involved in the disposal operations are represented in Figure 1. Sludge components, which contain most of the Sr-90 and long-lived actinides, will be washed and treated with sodium hydroxide in tank-farm operations to reduce aluminum hydroxide content, mixed with glass frit and fed as slurry to the DWPF melter.[2] The product of the DWPF melting operation is a borosilicate glass containing nominally 28 wt % waste oxides in stainless steel canisters about 60-cm diameter by 300-cm length.[4] For a representative glass composition, the DWPF output at 75% attainment is 410 canisters per year. Initial DWPF processing will be limited to wastes providing canister heat ratings less than 460 watts; after 5 years operation, wastes providing up to 690 watts/canister may be processed.

Soluble salt components of the wastes will be decontaminated in the waste tanks prior to solidification in concrete for onsite burial. In the salt decontamination operation, radiocesium (principally Cs-137) will be separated along with potassium in the wastes by precipitation as tetraphenylborate (TPB) salts, and residual Sr-90 and actinides will be removed by adsorption on sodium titanate.[3] The precipitated solids, concentrated by filtration and accumulated in the tank, will be treated using a formic acid hydrolysis process (termed "precipitate hydrolysis") to decompose the organic salt, and the product fed along with sludge components of the waste to the glass melter. After filling with glass, the DWPF canisters will be decontaminated, sealed, and stored onsite in a convection air-cooled vault, pending availability of a federal repository for permanent waste disposal.[4]

The decontaminated salt solution will be converted to solid form (termed "saltstone") by mixing with a blended cement for onsite burial as low level waste.[5] Salt solution will be processed at a rate of about 6 million gallons per year, including recycle washes. Saltstone facilities limit the age of salt solution processed to a minimum of 15-years following reactor discharge.

Following interim storage, the canisters in special casks are assumed to be shipped by truck or rail to the repository site at a rate equal to or somewhat in excess of the rate of DWPF production.[6] At the repository, the canisters will be packaged in appropriate overpack containers and emplaced for permanent disposal in underground facilities. In a representative case, the DWPF canisters would be buried in salt, tuff, or basalt geologic formations in conjunction with commercial nuclear wastes, using a repository design specially augmented to accommodate the defense wastes.[7]

III. SRP WASTE DISPOSAL COSTS

A. Cost Model

The cost model developed for SRP high-level waste disposal defines basic input parameters for the specific processing activities in the waste disposal system.[8] The input parameters include fixed and variable cost components for each activity, with variable cost components dependent on the quantity of waste (for example, number of waste canisters) processed annually. Since economic effects of the waste content of the glass waste forms arise primarily from changes in the number of waste canisters processed, only the variable costs associated with DWPF processing (including interim storage), offsite transport, and repository emplacement of the canisters are evaluated in this study. Variable costs associated with sludge washing, salt precipitation, and saltstone processing activities are not affected by changes in the number of canisters processed, and fixed costs representing capital expenditures for all the waste processing activities are considered constant.

B. Reference DWPF Operation

Derivation of incremental costs from input parameters of the cost model requires projection of reference operating scenarios for onsite and offsite waste processing facilities. For the onsite (DWPF) facilities, it is assumed that SRP reactors will operate at approximately the current level of waste generation to the year 2000. This is an arbitrary assumption of the cost model, since actual SRP operation will depend on demand for nuclear materials. For the year 2000 operation as represented in Figure 2, current and future inventories of waste will utilize full DWPF operating capacity until completion of sludge processing about the year 2005, following which the DWPF is assumed to be maintained in standby condition to allow batching of a residual inventory of 15-year aged salt for workoff in a final campaign. Typically 7500 canisters would be produced over the approximately 25 years of DWPF operation (including standby) required for processing waste sludge and salt generated to year 2000.

Incremental canisters resulting from adjustments of glass compositions impact the reference DWPF operating scenario by increasing (or decreasing) the time of full-capacity DWPF processing before shutdown (standby) on completion of sludge processing operations. For a nominal 3.5% decrease in the number of canisters produced (equivalent to 1% increase in canister waste content), the time of DWPF operation at full capacity is decreased by somewhat less than one year, as shown in Figure 2. Incremental costs assigned correspond to the difference in costs of full-capacity and standby DWPF operation over this period. The incremental annual costs of DWPF operation, summarized in Table 1, are about $46.4 million corresponding to $113,000 per canister.

C. Offsite Transport

Transport of the SRP waste canisters to a federal repository following interim onsite storage is projected in accord with previous studies.[8-10] Shipment of the SRP canisters contained in a single canister truck cask of appropriate design to a repository located in the Northwest is assumed at a rate of 500 canisters per year beginning about year 2000. The incremental canisters would be shipped and emplaced in the repository near the end of the SRP waste processing campaign in year 2015. Incremental costs estimated using updated tariff rates are projected in 1985 dollars at about $11,000 per canister.

D. Repository Packaging and Emplacement

Repository costs of SRP high-level waste disposal are projected on the assumption that the wastes will be emplaced in a commercial repository augmented to accommodate the defense waste canisters. As previously detailed,[7] emplacement of 7500 DWPF canisters in a salt, tuff, or basalt repository of standard design would require an underground area typically about 5% of that committed to the commercial high-level wastes. The incremental costs incurred under these circumstances are principally variable costs proportional to the number of DWPF canisters handled.

Prior to emplacement, the waste canisters would be packaged in appropriate overpack containers as required to meet regulatory requirements for the specific repository geology involved.[11] The overpack containers consist generally of carbon steel or stainless steel assemblies of sufficient thickness to withstand hydrostatic or lithostatic pressures of the repository, sometimes encased in a titanium alloy sheath for corrosion resistance.

The waste packages are assumed to be emplaced in boreholes excavated either vertically or horizontally in underground rooms or tunnels of the repository, with spacing dependent on heat output of the packages and thermomechanical properties of the geologic medium.[7] Placement room areas for defense wastes in vertical boreholes are typically 30 m^2 per package (15 to 23 W/m^2 for 460 to 690 watt DWPF canister) compared to commercial (spent fuel) wastes ranging from 85 to 250 m^2 per package (15 W/m^2) depending on heat output. The lower placement room areas compared to commercial wastes are a consequence of the lower heat loading (lower radioactivity content) of the defense waste packages. The defense waste packages are generally not emplaced at heat load limits for the repository because of mechanical constraints on borehole spacing, so that nominally increased waste loadings can be tolerated with the same placement room areas, especially for lower heat wastes processed in early DWPF operations.

A repository fee for defense waste disposal analogous to that charged utilities for commercial waste disposal is under current consideration in the Department of Energy. The fee established for commercial waste disposal, equal to 1.0 mill per kWh electricity generated using nuclear facilities, depends primarily on the quantity of radioactivity in the commercial wastes,

and not on the volume of waste or number of waste packages emplaced. An analogous assignment of repository fee for defense wastes would thus provide no dependence of repository costs on the number of waste canisters emplaced. Over the long term, however, the repository fee for defense waste must cover the real costs of disposal, so that reduced numbers of canisters emplaced would be reflected in lower repository fee assessments.

The real costs of repository emplacement of defense waste canisters are projected in the Savannah River model in two general categories, (1) direct costs representing incremental capital and operating expenditures and (2) indirect costs representing prorated charges assessed for use of facilities in common with commercial wastes.[7,8] Since incremental expenditures are of primary interest for evaluation of waste content effects, only the direct costs are considered in this study. Variable components of the direct costs dependent on the number of canisters emplaced include incremental expenditures for waste packaging components and operations, for mining of placement rooms and boreholes, for emplacement and monitoring operations, and for backfill operations. Such costs depend on repository geology, waste packaging requirements, and underground emplacement patterns. Representative values for SRP waste disposal are derived as average costs for canisters in steel overpacks emplaced in characteristic patterns (vertical or horizontal boreholes) in salt, tuff, and basalt repositories. The variable costs are projected in 1985 dollars at about $55,000/canister, including packaging costs of about $31,000/canister and mining and emplacement costs of $24,000/canister.

E. Incremental Costs of Increased Glass Waste Content

The cost impacts of increasing the waste content of DWPF glass are established by the foregoing projections. As shown in Table 1, costs dependent on the number of canisters processed, including costs of DWPF processing, offsite transport, and repository emplacement total $179,000 per canister. For a total of 7500 waste canisters produced by processing SRP waste generated to the year 2000, a nominal 1% increase in waste loading represents a decrement of 268 canisters, equivalent to $48 million in 1985 dollars in reduced waste disposal costs. Assuming DWPF processing of the incremental canisters about the year 2005 in accord with Figure 2 and transport and repository emplacement of the incremental canisters about the year 2015, present values of the incremental waste loading costs are $24 million and $5.5 million (1985 dollars) discounted at 3% and 10%, respectively.

Two modifications of waste loading are under current study at Savannah River. In a first modification now being optimized as the reference glass composition, precipitate hydrolysis product is substituted for frit rather than added as a waste component of the glass.[8] This reduces the frit content from 72 to 64% and effectively increases the waste content by about 8%. The accompanying decrease of 2200 waste canisters required for SRP waste generated to year 2000 results in a cost reduction of $394 million in 1985 dollars before discounting, with present values of $198 million and $45 million after discounting at 3% and 10%, respectively. Changes in frit composition at this waste loading needed to optimize properties of the glass do not additionally affect the cost reduction produced by the frit adjustment.

In a second modification, sludge-salt glasses with increased sludge content are being investigated. There are no present plans for increasing sludge loadings in the DWPF glass, but the cost effects indicate this may be a fruitful area for development after DWPF startup. An increase of the sludge content from 28 to 35% further decreases the frit content from 64% to about 57%, providing an additional 7% increase in waste content. The accompanying 1500 decrease in number of waste canisters produced for SRP reactor operation to the year 2000 results in a cost reduction of $269 million in 1985 dollars, with present values of $135 million and $31 million at discount rates of 3% and 10%, respectively.

The status of property measurements undertaken to optimize the compositions of the modified waste glasses is indicated in the following section.

IV. Optimization of Glass Waste Compositions

A. Frit-Adjusted Compositions

Optimization of the composition of the frit-adjusted sludge-salt glasses is necessary to provide acceptable processability and durability properties. Additions of precipitate hydrolysis product from the salt decontamination process introduces excess alkali (Na, K, and Cs) and boron oxides, tending to decrease melt viscosities during DWPF processing and increase leachability of the glass. Properties of the frit-adjusted sludge-salt glasses are being determined by measurement of viscosity and leachability of compositions with frit compositions selected to compensate for the precipitate hydrolysis product. Representative frit compositions, developed by modification of compositions previously optimized for sludge-only wastes,[13] are of three general types, illustrated in Table 3.

Results of both leach resistance (durability) and melt viscosity tests correlate with the molar ratio parameter (SiO_2)/ Σ (alkali + B_2O_3) of the glasses. As shown in Figure 3, the best leach resistance in deionized water is exhibited by sludge-salt glasses containing Types 2 and 3 frits with reduced alkali-B_2O_3 content. In accord with the molar ratio parameter, the durability of the Type 3 frit glasses (Table 3) is generally comparable to that of the current reference Frit 165 sludge-only glass. All the candidate sludge-salt glasses fall within calculated molar ratio parameter limits correlating empirically with acceptable melt viscosity values.

B. Increased Sludge Compositions

Increased sludge loadings up to 35 wt % produce leachabilities about the same as the reference 28 wt % waste loadings without deleteriously affecting viscosity in sludge-only glasses.[12] A similarly increased sludge loading may therefore be acceptable for the sludge-salt glasses. Durability tests of 35 wt % sludge glasses with adjusted frit compositions analogous to those of Table 3 are in progress, and other property measurements including

melt viscosity are projected. Preliminary results included in Figure 3 show leachabilities for sludge-salt glasses with 35 wt % sludge content comparable to those with 28 wt % sludge content. Minimum leachability values with modified frit compositions are equivalent to those for the optimized Frit 165 sludge-only glass. Such results suggest that acceptable sludge-salt glasses with increased sludge content may be feasible for future DWPF operations.

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REFERENCES

1. R. Maher, L. F. Shafranek, J. A. Kelley, and R. W. Zeyfang, "Solidification of Savannah River Plant High Level Waste," Trans. Am. Nucl. Soc, 39, 228 (1981).

2. M. D. Boersma, "Process Technology for Vitrification of Defense Waste at Savannah River," Proceedings - Fuel Reprocessing and Waste Management, Jackson, Wyoming, August 1984, Vol. 1, p. 131, American Nuclear Society.

3. L. M. Lee and L. L. Kilpatrick, "Precipitation Process for Decontamination of Water Soluble SRP Radioactive Waste," Trans. Am. Nucl. Soc., 43, 124 (1982); H. D. Martin, M. A. Schmitz, M. A. Ebra, D. J. Walker, L. E. Lee and L. L. Kilpatrick, "In-tank Precipitation Process for Decontamination of Water-Soluble SRP Radioactive Waste," Waste Management 84: Waste Isolation in the U.S., Technical Programs and Public Education, Tucson, Arizona, March 1984, Vol. 1, p. 291, Univ. of Arizona.

4. R. G. Baxter, R. Maher, J. B. Mellon, L. F. Shafranek, and W. R. Stevens, III, "The Defense Waste Processing Facility at the Savannah River Plant," Waste Management 84: Waste Isolation in the U.S., Technical Programs and Public Education, Tucson, Arizona, March 1984, Vol. 1, p. 275, Univ. of Arizona.

5. C. A. Langton, M. D. Dukes and R. V. Simons, "Saltstone: Cement-Based Waste Form for Disposal of SRP Low-Level Waste." Waste Management 84: Waste Isolation in the U.S., Technical Programs and Public Education, Tucson, Arizona, March 1984, Vol. 1, p. 297, Univ. of Arizona.

6. The Defense Waste Management Plan, U.S. Department of Energy, DOE/DP-0015, June 1984.

7. W. R. McDonell, "Costs for Disposal of Savannah River High-Level Waste in a Commercial Repository," Waste Management 84: Waste Isolation in the U.S., Technical Programs and Public Education, Tucson, Arizona, March 1984, Vol. 1, p. 553, Univ. of Arizona.

8. W. R. McDonell and C. B. Goodlett, "Systems Costs for Disposal of Savannah River High-Level Waste Sludge and Salt," Proceedings - Fuel Reprocessing and Waste Management, Jackson, Wyoming, August 1984, Vol. 1, p. 414, American Nuclear Society.

9. High Level Waste Transportation System Development Program, Final Report for Fiscal Year 1980, General Atomic Company, GA-A-16124, January 1981.

10. W. B. Andrews, B. M. Cole, R. L. Engel and J. M. Oylear, Defense Waste Transportation Cost and Logistics Studies, Battelle Memorial Institute, Pacific Northwest Laboratory, PNL-3721, August 1982.

11. Advanced Energy Systems Division, Westinghouse Electric Corp., Engineered Waste Package Conceptual Design: Defense High-Level Waste (Form 1), Commercial High-Level Waste (Form 1), and Spent Fuel (Form 2) Disposal in Salt, ONWI-438 (1983); Waste Package Conceptual Designs for a Nuclear Repository in Basalt, RHO-BW-CR-136P/AESD-TME-3142 (1982); Conceptual Waste Package Designs for Disposal of Nuclear Waste in Tuff, ONWI-439 (1983).

12. W. D. Rankin and G. G. Wicks, "Chemical Durability of Savannah River Plant Waste Glass as a Function of Waste Loading," J. Am. Ceram. Soc., 66, 389, 1983.

13. P. D. Soper, D. D. Walker, M. J. Plodinec, G. J. Roberts and L. F. Lightner, Optimization of Glass Composition for the Vitrification of Nuclear Waste at the Savannah River Plant, Am. Ceram. Soc. Bulletin, 62 (9), 1013 (1983).

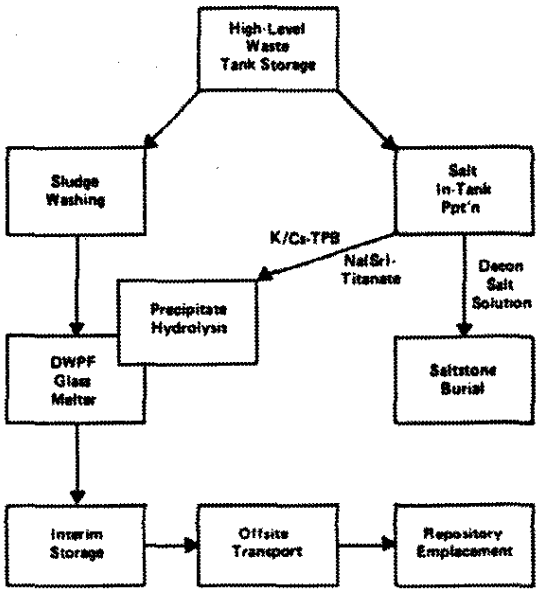

Figure 1. Reference High-Level Waste Disposal Activities

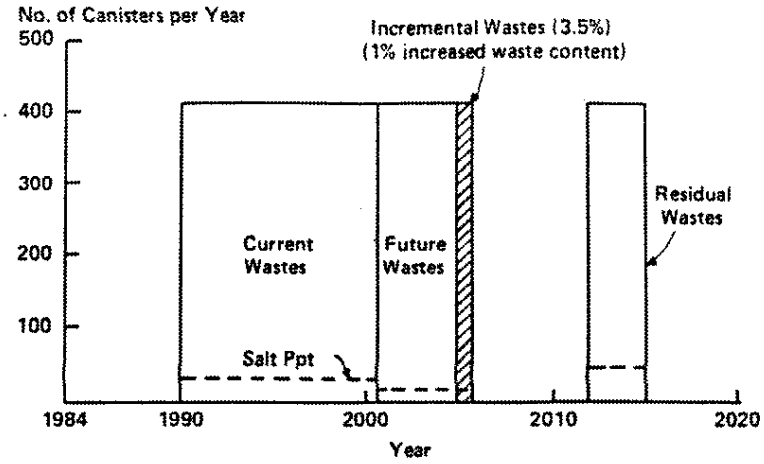

Figure 2. Schedule for Processing Year 2000 High-Level Waste Inventory DWPF Canisters

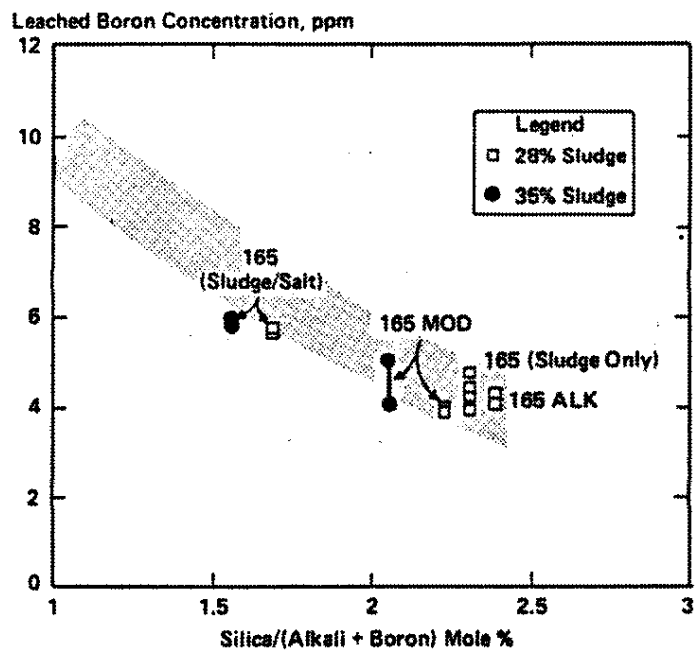

Figure 3. Durability of Sludge-Salt Glasses in Deionized Water (MCC 28-day Static Test). Leached boron concentrations are shown as function of the molar ratio parameter for glasses containing modified frits given in Table 3. Background shading indicates general dependence of leachability on the molar ratio parameter of SRP glasses.

Table 1. Incremental Costs of SRP High-Level Waste Disposal Activities

Activity	Incremental Costs, 10^3 \$ (1985)	
	Annual	Unit*
DWPF Operation	46,400	113.2
Offsite Shipment	-	11.0
Repository Emplacement	-	55.0
Total		179.2

* Unit costs assume 410 DWPF canisters per year.

Table 2. Cost Impact of Increased Waste Content in DWPF Glass

Waste Content Increase	Incremental Canisters	Cost Reduction, 10^6 \$ (1985)*		
		Nominal	Present Value 3%	Present Value 10%
Unit (1 wt %)	268	48	24	5.5
Frit Adjustment (8 wt %)	2200	394	198	45
Increased Sludge (7 wt %)	1500	269	135	31

* SRP wastes generated to year 2000.

Table 3. Frit Compositions for Sludge-Salt Glasses*

Component	Type 1 (Frit 165)	Type 2 (Frit 165 Mod)	Type 3 (Frit 165 Alk)
SiO_2	68	76	77
Na_2O	13	10	6
Li_2O	7	6	7
B_2O_3	10	7	8
MgO	1		
ZrO	1	1	2

* Reference frit 165 for sludge-only glasses modified for sludge-salt glasses: Type 1 - Frit content decreased with unchanged composition; Type 2 - Frit composition decreased in alkali and boron oxides to compensate for Na_2O, Cs_2O, and B_2O_3 in the precipitate hydrolysis product; Type 3 - Frit composition additionally decreased in alkali and boron oxides to compensate for K_2O in the precipitate hydrolysis product.