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ABSTRACT

Recently developed reference schedules for processing high level nuclear wastes into solid glass forms at Savannah River provide bases for economic evaluations of potential improvements of glass melter design and operation. Greater melter output is achieved through increases in capacity and attainment† and possibly higher glass waste loadings. The economic evaluation indicates only minor beneficial impacts on total waste disposal costs for melter outputs greater than current reference values. In contrast, cost impacts are detrimentally large for outputs less than reference values, providing important incentives for development to ensure the reference output. The limits on cost benefits for greater-than-reference output are not intrinsic to melter design or product composition, but are derived from restrictions on melter feed specified to control radiation and heat loads of the product glass waste form.

INTRODUCTION

The Defense Waste Processing Facility (DWPF) under construction at Savannah River is designed to convert large quantities of high level radioactive wastes into solid glass forms for final disposal in a geologic repository. Future costs of the process are projected to aid in the specification of optimum equipment and procedures. The purpose of this paper is to update a cost model using projected material and radioactivity flows through the waste glassmaking operations[1,2] and to demonstrate the utility of the model by evaluating economic incentives for improved glass melter operation.

BACKGROUND

Savannah River wastes are currently contained onsite as aqueous sludges and salts in large steel tanks[3]. The primary product of the DWPF operation is a borosilicate glass of nominally 28 wt % waste oxides contained in large (24 in. dia by 10 ft high) stainless steel canisters[4-7]. Supporting the DWPF glassmaking operation are in-tank treatments of the sludges and salt wastes[8], including separation of soluble radioactive salt constituents by in-tank precipitation[9] to prepare them as feed for the DWPF, and the concurrent processing of decontaminated solutions to a solid concrete form (saltstone) for onsite disposal[10].

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† Days of capacity operation/365 days.

Cost projections for conversion of radioactive wastes to glass are based on predicted DWPF output over the time necessary to work off current and future waste inventories. Waste glass output is potentially limited by capacity specifications and attainment for the DWPF glass melter, by radiation shielding of the DWPF containment structures housing the processing equipment, and by heat loads permitted for the product glass waste canisters. Nominal glass melter output is 228 lb of waste glass per hour, equivalent (at 75% attainment) to 410 canisters per year. In previous projections[1,2], the quantities of waste aged to meet the radioactivity limitations were deemed sufficient to allow DWPF output at the nominal melter capacity until near completion of processing of projected waste inventories. Costs dependent on the number of canisters produced were simply calculated from the number of years of DWPF operation (at specified annual costs) required for processing projected waste inventories. For a typical waste inventory produced by SRP reactors to year 2000, the DWPF was assumed to operate at nominal melter capacity from startup about 1990 to completion of waste processing about 2005[2].

REVISED COST MODEL

DWPF Output Schedule

The radioactive wastes in SRP tanks derive from several chemical processing streams, representing different radionuclide contents. Segregated by tank and concentration processes, the wastes also vary in radioactive age. DWPF feed is prepared by selection and blending of wastes of low and high heat content, with age taken into account. Radioactivity limits on the waste feed streams (principally sludge) will require turndown of DWPF glass melter outputs at a time significantly earlier than required for completion of processing of projected waste inventories. For typical waste inventories generated to year 2000, the revised DWPF schedule projects operation at nominal glass melter capacity (410 canisters per year) to about year 1998 (2870 accumulated canister output), followed by turndown to about half maximum melter output (205 canisters per year) to year 2008 (4920 total canister output). Depending on details of projected reactor schedules, some quantities of residual wastes (essentially high heat wastes) will remain unprocessed at this time. Since requirements for processing the residual wastes (using lower waste content glasses, for example) have not been specified, DWPF melter outputs in the terminal regime are not included in the DWPF model schedule. The DWPF output schedule employed in the revised cost model is represented graphically in Figure 1. Incremental quantities of waste generated are assumed to extend DWPF operation at turndown output as illustrated in the figure.

Similar projected output schedules for the supporting in-tank sludge and salt precipitation processing and for concurrent saltstone processing operations are available for comprehensive economic evaluations of the SRP waste processing operations but are not used in the following assessments of glass melter optimization.

Cost Assignments

Cost assignments for onsite DWPF operation are based on previous economic assessments[2], updated to incorporate planned changes in operation. Basic cost categories include materials, utilities, manpower, and overhead. Charges in each cost category are specified by the following formula:

$$A = A_O + (A_T - A_O)\,(N/N_r)^P, \quad 0 < P < 1$$

where:

A = annual costs at output N canisters/yr

A_O = annual fixed costs

A_T = total costs at reference output N_r canisters/yr

N = actual output (canisters/yr)

N_r = reference output (410 canisters/yr)

P = power dependence of annual costs on output

Values of input constants assumed for DWPF operation are as follows:

Cost Category	Million \$ A_T	Million \$ A_O	P
Materials	4.865	0	1
Utilities	4.017	0	1
Manpower	20.960	2.096	0.5
Overhead	42.207	4.221	0.5
Total	72.049		

The 0.5 exponential dependence of manpower (and related overhead) costs represents a generalization of several estimates made for specific levels of reduced DWPF operations.

For optimizations that affect the total number of DWPF canisters produced, offsite costs of transport and repository disposal are also evaluated. Costs for disposal of the defense wastes are to be paid by the Federal Government into the Nuclear Waste Fund, using an allocation procedure based essentially on the total number of canisters produced[11,12]. Using current methodology, the offsite costs will be charged incrementally at approximately \$320,000 per canister.

A typical compilation of costs for wastes generated by the reference scenario is shown in Table 1. Total DWPF costs for production of 4920 canisters to year 2008 is \$1014 million, equivalent to an average cost of \$206,000 per canister. Offsite costs assessed at \$320,000 per canister (\$1574 million) bring total costs to \$2588 million, for an average disposal cost of \$526,000 per canister. An incremental 5% quantity of waste processed (246 canisters) would affect DWPF costs by \$61 million dollars, equal to about \$250,000 per canister. Total costs including offsite costs of the incremental canisters would be about \$140 million, equal to \$570,000 per canister.

EVALUATION OF MELTER OPTIMIZATIONS

Reduced costs of waste glass processing can potentially be achieved by improvements in DWPF glass melter operations[13,14]. On the positive side, melter improvements can result in increased output capacity, increased attainment, or increased glass waste loadings. Such cost impacts provide incentives for process improvement, but do not ensure the projected benefits, since technical limitations may apply. On the negative side, the cost impacts can indicate economic penalties to be sustained by deficient melter operation. Use of the revised DWPF cost model to evaluate these factors is illustrated in the following sections.

Capacity Factor

Improvements of melter design and operation to achieve optimum melt rates can affect costs by increasing capacity output (reference output 228 lb of glass per hour). Assuming analogous upgrades of supporting processes, DWPF operating costs are evaluated as a function of melter capacity factor by adjusting the output parameter (N) in the model formula for each cost category (materials, utilities, manpower, and overhead). For capacity factors greater than 100%, the DWPF is assumed to operate at the reference output for an initial two years, followed by the increased output until turndown; turndown is projected at the same or lower number of accumulated canisters and the same annual canister output as for the reference operation. For capacity factors less than 100%, initial operation at the reduced capacity is assumed, and turndown is projected at somewhat greater than the accumulated canister output for the reference operation (no turndown for 50% capacity factor).

The resulting DWPF glass costs are represented over capacity factors ranging from 50 to 150% (114 to 342 lb glass/hr) in Figure 2A. Increases in capacity factors above nominal 100% have a smaller cost impact (typically - $42 million for increases to 125% capacity) than decreases below 100% (typically + $209 million) for decreases to 50% capacity. Operation at reference capacity thus approaches optimum (minimum) costs, but at lower-than-reference capacity results in large cost penalties.

Attainment Factor

Improved melter design and operation can affect attainment by increasing useful life and decreasing downtime for repair. Costs are evaluated as a function of the attainment factor by adjustment of output parameter (N) for material and utilities in the model formula, while holding N for manpower and overhead constant at the reference value. Incremental changes in attainment are thus assumed to occur with no change in supporting manpower. For attainment factors greater than reference 75%, the DWPF is again assumed to operate at the reference output for an initial two years, followed by operation at increased attainment until turndown. The turndown conditions for the attainment factor calculations are assumed to be the same as for the capacity factor calculations. Resulting DWPF costs are shown in Figure 2B, depicting for the attainment factors similar but more pronounced trends as for the capacity factors. Increased attainment up to 100% has a smaller cost impact (about - $34 million) than decreased attainment, with the latter ranging up to + $609 million at 37.5% (half reference) attainment. Attainment increases thus produce limited cost benefits, but attainment decreases result in very high economic penalties.

Waste Loading

Improvements in melter design that allow increased melter temperatures, for example, can increase waste loadings of the glass. The limits on waste loading, including the reference waste loading (28 wt %), are assumed to be established by factors other than canister radioactivity and heat loads, e.g., by melt viscosity and crystalline phase content. Calculations of cost impacts associated with glass waste loading must take into account the variation in total number of canisters required for a given quantity of waste, as well as the annual DWPF output requirements. For canisters with increased glass waste loading, an initial two years of DWPF operation at reference glass waste loading is assumed, followed by operation at higher waste loadings until turndown at the same accumulated output as the reference case; after turndown, operation at the reference waste loading is assumed because canister radioactivity and heat loads determine turndown requirements. For canisters with decreased glass waste loadings, no initial operation at reference waste loading occurs before turndown, and after turndown DWPF output higher than the reference case is assumed* because radiation and heat loads may not be limiting in this case. Results in Figure 3 indicate, in common with the other melter operating parameters, that cost impacts for waste loadings greater than the reference value are less pronounced than for waste loadings less than the reference value. Higher loadings up to 35 wt % decrease the DWPF costs by $72 million, but lower loadings at 21 wt % increase costs by about $235 million.

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* For 21 wt % loading, turndown is delayed three years to 308 canisters per year; for 14 wt % loading, no turndown (410 canisters per year) is assumed.

Changes in parameters such as waste loading that affect the total number of canisters have impacts on offsite (transport and repository) costs as well as onsite DWPF costs. The effects of waste loading on offsite costs, evaluated using the same output assumptions as for the onsite costs, are also shown in Figure 3. As for the onsite costs, offsite cost impacts are less at waste loadings greater than the reference value than at waste loadings less than the reference value. Because offsite unit costs are greater than onsite unit costs, however, the magnitude of the offsite cost impact is greater than the onsite cost impacts. Total onsite and offsite costs are represented as a function of waste loading in Figure 3, indicating cost decreases of $203 million for waste loadings of 35 wt % and cost increases about $760 million for waste loadings of 21 wt %.

INTERPRETATION

It is evident from the foregoing evaluations that in each case the specified reference parameters represent near optimum conditions for the waste processing scenarios projected. This is a direct result of the limited time of DWPF operation at the nominal output permitted by restrictions on radioactivity and heat loadings of the product canister. The apparent optimization of process parameters does not represent intrinsic limits on output for either the melter operation or the glass composition but is due to the turndown requirements built into the reference DWPF schedule. It is the DWPF schedule, determined by radioactivity limits of the feed streams due to product handling restrictions, that is optimized. This is illustrated by the waste loading evaluation, where the cost benefits of higher loadings (if technically possible) are diminished by output turndown required by feed radioactivity. Since no such restrictions apply for lower waste loadings, the cost impacts (penalties) of lower waste loadings are dramatically greater. Similar considerations apply to cost impacts for melter capacity and attainment factors, which are also low at greater-than-reference values, but are high at less-than-reference values. The key to economic improvement of DWPF glassmaking operations lies in measures that would allow processing of higher radioactivity feed. These measures could include supplemental shielding in critical DWPF exposure areas and design or operation of the storage vault to permit interim storage of higher heat-load canisters. Such measures would delay turndown requirements in the DWPF waste processing schedule and allow improvements in melter design and glass composition, where technically feasible, to be undertaken with full economic benefit.

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Table I. Costs of SRP Waste Processing for Reference DWPF Schedule (Melter Capacity 228 lb/hr, Attainment 75%, Glass Waste Content 28%)

Year	No. of Canisters	Total Canisters	Operating Costs, million $ Materials	Utilities	Manpower	Overhead	Total	Disc. Factor (10%)	Disc. Costs
1987								1.000	
1988								0.909	
1989								0.826	
1990								0.751	
1991	410	410	4.865	4.017	20.960	42.207	72.049	0.683	45.967
1992	410	820	4.865	4.017	20.960	42.207	72.049	0.621	44.742
1993	410	1230	4.865	4.017	20.960	42.207	72.049	0.565	40.708
1994	410	1640	4.865	4.017	20.960	42.207	72.049	0.513	36.961
1995	410	2050	4.865	4.017	20.960	42.207	72.049	0.467	33.647
1996	410	2460	4.865	4.017	20.960	42.207	72.049	0.424	30.549
1997	410	2870	4.865	4.017	20.960	42.207	72.049	0.386	27.811
1998	205	3075	2.433	2.009	15.435	31.081	50.958	0.351	17.886
1999	205	3280	2.433	2.009	15.435	31.081	50.958	0.319	16.256
2000	205	3485	2.433	2.009	15.435	31.081	50.958	0.290	14.779
2001	205	3690	2.433	2.009	15.435	31.081	50.958	0.263	13.402
2002	205	3895	2.433	2.009	15.435	31.081	50.958	0.239	12.179
2003	205	4100	2.433	2.009	15.435	31.081	50.958	0.218	11.109
2004	205	4305	2.433	2.009	15.435	31.081	50.958	0.198	10.090
2005	205	4510	2.433	2.009	15.435	31.081	50.958	0.180	9.172
2006	205	4715	2.433	2.009	15.435	31.081	50.958	0.164	8.357
2007	205	4920	2.433	2.009	15.435	31.081	50.958	0.149	7.593
						Total Cost	1013.923		381.208
	Residual	480							
	Total Inv[a]	5400							

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[a] Year 2000 waste inventory.

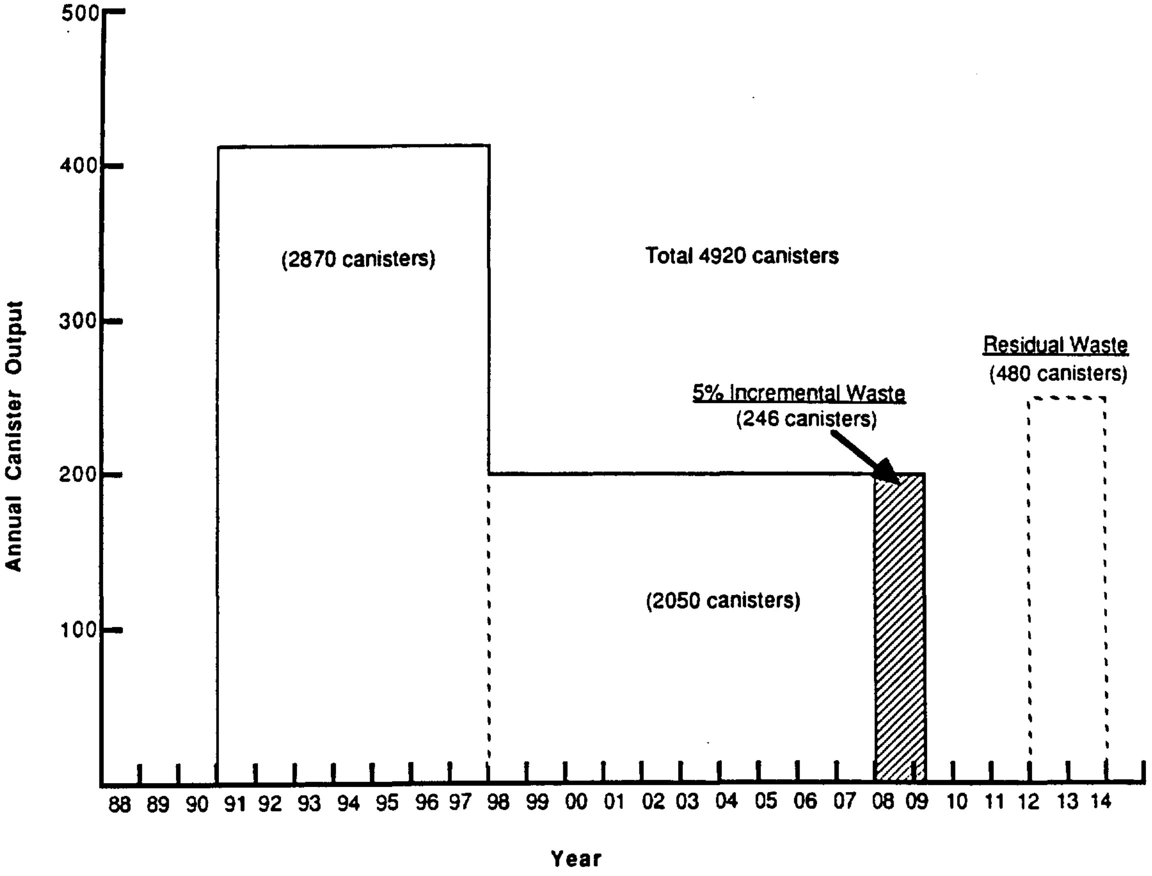

Figure 1. Reference DWPF Output Schedule for Revised Cost Model (Year 2000 Waste Inventory)

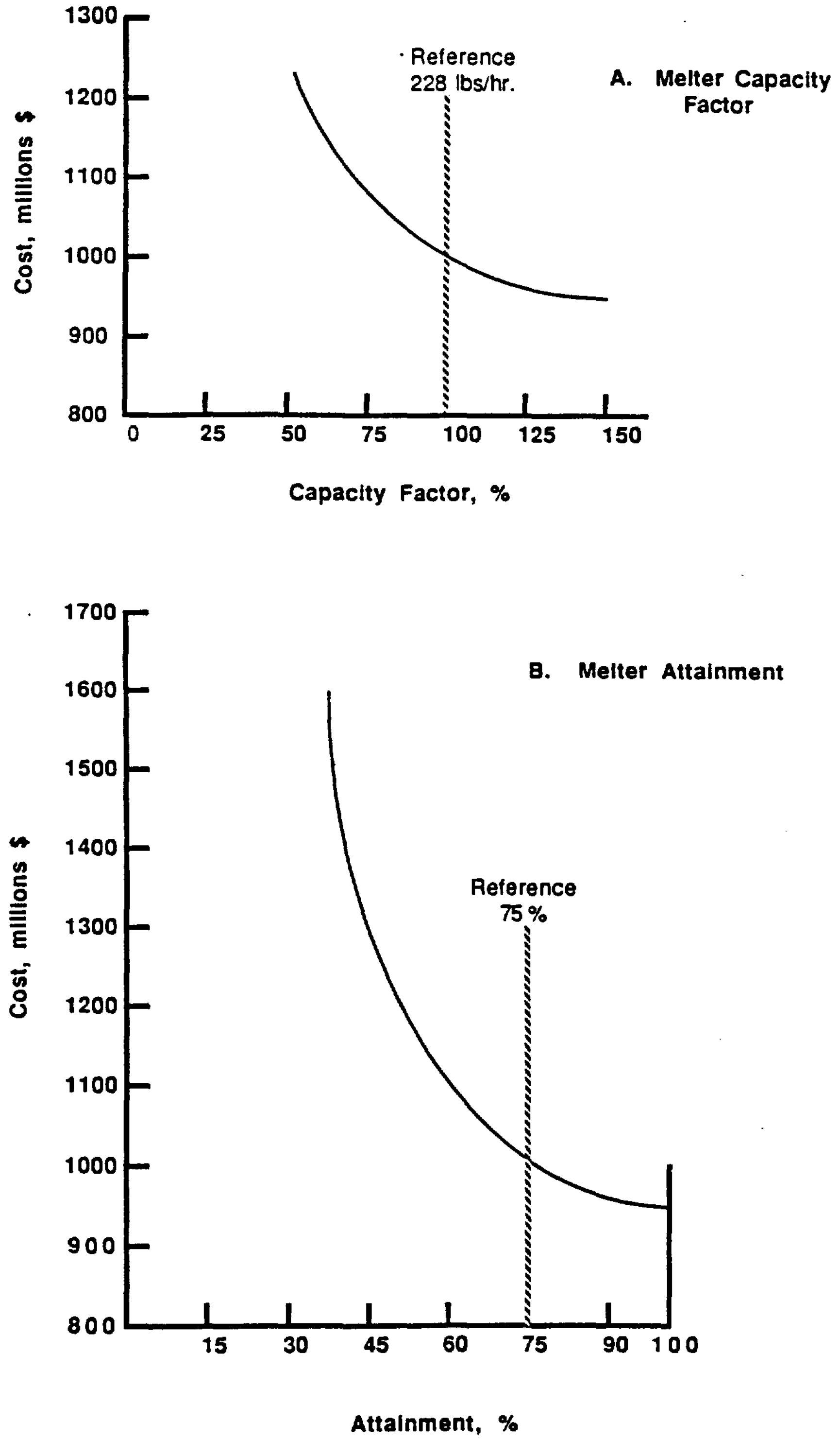

Figure 2. Effect of Melter Parameters on Total DWPF Operating Costs (4920 Canisters)

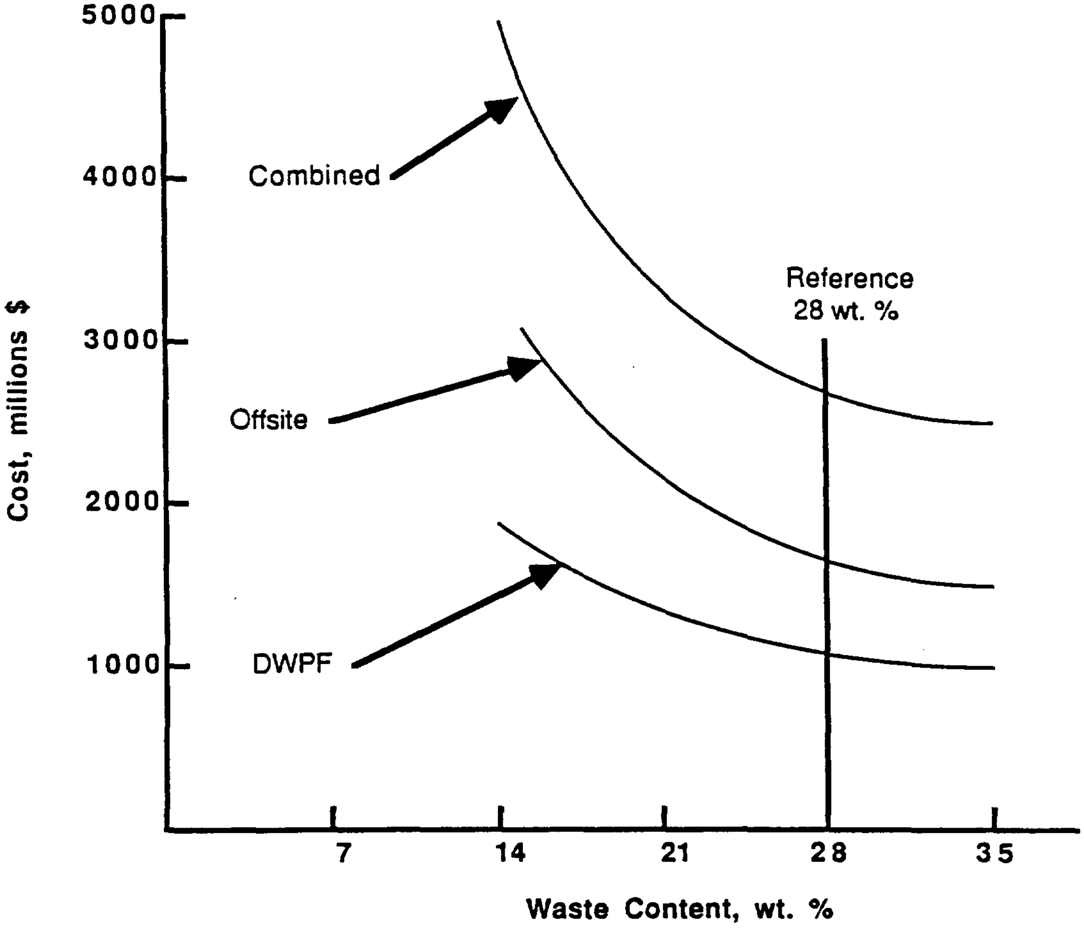

Figure 3. Effect of Glass Waste Content on DWPF, Offsite (Repository), and Combined Waste Disposal Costs