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DESCRIPTION OF DEFENSE WASTE PROCESSING FACILITY REFERENCE WASTE FORM AND CANISTER

RICHARD G. BAXTER

Waste Management Programs

E. I. du Pont de Nemours & Co.
Savannah River Plant
Aiken, SC 29808

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ABSTRACT

This document describes the reference waste form and canister for the Defense Waste Processing Facility (DWPF). The facility will be located at the Savannah River Plant in Aiken, SC, and is scheduled for construction authorization during FY-1984.

The reference waste form is borosilicate glass containing approximately 28 wt % sludge oxides, with the balance glass frit. Borosilicate glass was chosen because of its high resistance to leaching by water, its relatively high solubility for nuclides found in the sludge, and its reasonably low melting temperature. The glass frit contains approximately 58% SiO_2 and 15% B_2O_3. Leachabilities of SRP waste glasses are expected to approach 10^{-8} g/m^2-day based upon 1000 day tests using glasses containing SRP radioactive waste. Tests were performed under a wide variety of conditions simulating repository environments. The canister is filled with 3,260 lb of glass which occupies about 85% of the free canister volume. The filled canister will generate approximately 470 watts when filled with oxides from 5 year old sludge and 15 year old supernate from the sludge and supernate processes.* The radionuclide content of the canister is about 177,000 curies, with a radiation level of 5500 rem/hour at canister surface contact.

The reference canister is fabricated of standard 24 in.-OD, Schedule 20, 304L stainless steel pipe with a dished bottom, domed head, and a combined lifting and welding flange on the head neck. The overall canister length is 9 ft 10 in. (300 cm) with a wall thickness of 3/8-in. The canister length of 3 meters was selected to reduce equipment cell height in the DWPF to a practical size. The canister diameter was selected as an optimum size from glass quality considerations, a logical size for repository handling and to ensure that a filled canister with its double containment shipping cask could be accommodated on a legal-weight truck. The overall dimensions and weight appear to be compatible with preliminary assessments of repository requirements.

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* Sludge processing was previously designated as Stage 1 and supernate processing was designated as Stage 2 in the June 1981 issue of DP-1606.

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INTRODUCTION

This document describes the reference glass waste form and the canister planned for the Defense Waste Processing Facility (DWPF). The borosilicate glass waste form and steel canister are the basis for the September 1982 design and budget quality cost estimate for the facility, and is the reference form selected in December 1982 for the DWPF.

HLW FORM CHARACTERISTICS

The reference waste form for the DWPF is a borosilicate glass containing approximately 28 wt % sludge oxides with the balance being glass frit. Borosilicate glass was chosen as a waste form because of its resistance to leaching by water, its relatively high solubility for nuclides found in the sludge, its relatively low melting temperature, and because the process is based upon well-developed technology.

Description of the waste glass characteristics is divided into three sections: composition, mechanical properties, and leachability. Glass composition is further divided by sludge processing and sludge-supernate processing. Sludge processing is based upon processing just the 5 year old or older waste sludge. Sludge-supernate processing is based upon processing the 5 year old or older sludge plus a 15 year old or older supernate fraction containing virtually all of the Cs-137. Mechanical properties of the waste glass are based upon the current frit candidate, designated as Frit 131.

Data on leachability described in this report are from tests using earlier frit compositions designated as Frit 18 and Frit 21. Current leachability tests are being performed with Frit 131 and a new Frit 165, and also incorporate testing procedures recommended by the Materials Characterization Committee. Final results of the tests will be issued as they become available, but results to date indicate that properties of Frits 18 and 21 are comparable with Frits 131 and 165 glass.

COMPOSITION OF DWPF WASTE GLASS

Feed to the DWPF is divided into two processes: settled, washed sludge is the feed for the DWPF sludge process. This feed consists only of waste tank sludges containing nearly all of the stable and radioactive fission products, actinide elements, and elements added in the separations processes (primarily Fe, Mn, Al, and Hg). The sludge is treated with sodium hydroxide to dissolve hydrated aluminum oxides, washed with water to remove soluble salts to 2 wt % on a dry basis, and then allowed to settle.

In the supernate process, the liquid fraction is processed. The supernate portion contains the soluble salts, including the Cs-137 fraction. The supernate portion is the bases for the salt plant feed processing.

Sludge Processing

A description of the chemical composition of sludge plant feed is in Table 1, the radionuclide content in Table 2, and the isotopic content in Table 3. The soluble solids are principally NaOH (32%), $NaNO_3$ (29%), $NaAlO_2$ (16%), and $NaNO_2$ (12%), which constitute about 88 wt % of the solids in this fraction. Of the insolubles, $Fe(OH)_3$ (38%), $Al(OH)_3$ (16%), and SiO_2 (7%) constitute approximately 61 wt % of the solids in this fraction. Activity of the sludge plant feed is 163 Ci/gal with a decay heat of 0.47 watt/gal for 5-year aged waste. Of this activity, 74% is due to Sr-90, Y-90, and Pm-147.

Chemical composition of the sludge processing glass waste form is described in Table 4, the radionuclide content is shown in Table 5 and the isotopic content in Table 6. The total activity is 42.7 Ci/lb, with a decay heat of 0.122 watt/lb for 5-year old waste. Thus, the 3,260-lb canister with sludge processing waste glass contains about 139,000 Ci with a decay heat of 399 watts. The isotopes of Sr-90, Y-90, and Pm-147 contribute about 74% to the waste-form activity.

Supernate Processing

A description of the chemical composition of the supernate feed is in Table 7, the radionuclide content of feed from the supernate process is shown in Table 8, and the isotopic content in Table 9. The soluble solids are principally $NaNO_3$ (40%), $NaOH_2$ (17%), and $NaNO_2$ (16%) which constitute about 73 wt % of the solids in this fraction. Of the insolubles, $Al(OH)_3$ (33%) and $Fe(OH)_3$ (30%) represent approximately 63 wt % of the solids in this fraction. Activity of the feed from the supernate process is

464 Ci/gal with a decay heat of 1.08 watt/gal for 15-year-old supernate. Of this activity, over 99% is due to Cs-137 and its beta decay daughter, Ba-137m.

The chemical composition of combined sludge and supernate waste glass is shown in Table 10, the radionuclide content is shown in Table 11 and the isotopic content in Table 12. Total activity is 54.2 Ci/lb with a decay heat of 0.144 watt/lb for 5-year-old sludge and 15-year-old supernate. Thus, the 3,260-lb canister with both stages contains about 177,000 Ci with a decay heat of 470 watts. The isotopes of Y-90, Sr-90, Cs-137, Ba-137m, and Pm-147 contribute about 85% of the activity.

Chemical composition of the current reference frit, designated as Frit 131, is shown in Table 13. The frit is approximately 58% SiO_2, 18% Na_2O, and 15% B_2O_3. The frit was developed after an extensive series of tests designed to produce a waste glass product with good leach resistance, high solubility for waste oxides, and a practical melting temperature.

A second frit designated as Frit 165 is currently under evaluation. The new frit contains 68% SiO_2 for further reduction in leachability. Processing studies are in progress at SRL.

PHYSICAL PROPERTIES OF DWPF WASTE GLASS

Physical properties of DWPF waste glass have been measured and also estimated by calculation. Most of the properties determined by experiment are based upon Frit 21 rather than the current reference Frit 131, however there are few significant differences. The principal differences between the two is that Frit 131 is higher in percent of SiO_2 and B_2O_3, but lower in TiO_2 than Frit 21. In addition, La_2O_3, MgO, and ZrO_2 were incorporated into Frit 131 to improve glass durability. A chemical comparison between several of the frits evaluated is shown in Table 13.

Physical properties of glass waste forms are listed in Table 14. Of these values, the fractional thermal expansion, the density at 100°C, and the softening point were experimentally determined for Frit 131 glass. Other values are based on Frit 21 or other typical compositions.

Several physical properties of SRP waste glasses have not been determined experimentally, but have been estimated by calculation. Heat capacity, thermal conductivity and density for three types of DWPF waste glass (composite, high iron, and high aluminum) have been calculated on the basis of glass containing approximately 28% sludge oxides and the balance glass Frit 131. Typical compositions for these three types of glass are shown in Table 15.

Heat Capacity

Calculated heat capacities of simulated waste glasses are listed in Table 16. Cpm is the mean heat capacity referenced to 0°C; Cpt is the true heat capacity at the indicated temperature. True specific heat as a function of temperature is shown in Figure 1.

Density

Measured densities for simulated waste glass are listed in Table 17 and calculated densities are listed in Table 18. The property transition temperature, Tr ≅450°C, is approximate and differs somewhat for each type of glass. At this temperature some properties, as density and thermal expansion, change rapidly with temperature. Density as a function of temperature is shown in Figure 2.

Thermal Conductivity

Thermal conductivity of a substance is a measure of the heat transferred through a substance by conduction. The calculated radiative and effective thermal conductivity is described in Table 19. The change in values around 700°C is due to the increasing effect of radiant conductivity. Thermal conductivity as a function of temperature is shown in Figure 3.

Electrical Resistivity

Measured electrical resistivity of the glass melt as a function of temperature is shown in Figure 4. At the operating melt temperature of 1150°C, the resistivity is approximately 2.5 ohm-cm for composite glass.

Thermal Expansion

Waste glass measured thermal expansion as a function of temperature is shown in Figure 5 for composite sludge glass, in Figure 6, for High-Al glass, and in Figure 7 for High-Fe glass.

Viscosity

Experimentally determined viscosities for the three types of simulated waste glass are shown in Figure 8. At the nominal operating temperature of 1150°C, the composite glass viscosity is about 8 poise.

LEACHABILITY STUDIES ON DWPF WASTE GLASS

Studies on glass leachability have been in progress at the Savannah River Laboratory for the past ten years as part of a program investigating the properties of glasses containing radioactive waste.

Leaching characteristics of SRP simulated and actual waste glasses are described in detail in report DP-1629 (See reference section). Figure 9 describes published leach rates of SRP glasses with brine and distilled water at 25°C and 90°C for periods up to 375 days. Initial ^{137}Cs leach rates of 10^{-1} grams of glass/m^2-day decreased to about 5×10^{-5} by 375 days.

Experimental data based upon Cs-137 on actual SRP waste glasses are described in Figure 10. Waste from tanks 4, 5, 6, 13, 15, and 16 was encapsulated into Frits 18 and 21 at waste loadings of 35 and 40%. Cumulative leaching, based upon Cs-137, varied between 0.07-1.0 g/m^2. Similar data based upon Sr-90 is shown in Figure 11, and for Pu in Figure 12.

Leachability of SRP waste glasses has been studied using three types of tests. Most of the earlier work was done either with Soxhlet tests or those recommended by the International Standards Organization and the International Atomic Energy Agency. Current studies are based upon more standardized leaching procedures developed by the Materials Characterization Center.

Glass Cracking

Since the total amount of material leached is related to the surface area, glass fracture during cooling has been investigated at Battelle-Pacific Northwest Laboratories (PNL) and at SRL. Tests have shown that cracking can be reduced by the use of canister materials that match the glass coefficient of thermal expansion, by the use of canister deformable liners, by slow cooling through the annealing range, and by annealing the solidified form. Based upon data from tests at SRL, the glass surface area increases by about a factor of 25 due to cracking when cooled in ambient air at an average rate of 12°C/hr. However, theoretical and experimental studies indicate that the fraction of radionuclides leached will only increase by a factor of 5. Measured leach rates and cumulative leaching of actual SRP waste glasses are shown in Figures 9 through 12.

Repository Temperature

The most radioactive waste planned for processing in the DWPF is aged 5 years, out of reactor. For sludge plus supernate processing, the heat generated per canister is 470 watts, or 0.753 watt/L of glass. Salt repository studies indicate that with this low power density the canister surface temperatures will be below 110°C for a canister spacing of approximately 7.5 feet. Consequently, glass structural changes due to temperature will be negligible.

Radiation Stability

During long-term storage, the glass waste form will be continuously irradiated by beta-gamma emissions from fission products and by alpha emissions from transuranic nuclides. The estimated dose during the storage period of 1×10^6 years is calculated to be 14×10^{10} rads. Results of radiolysis studies indicate that this dose rate has an insignificant effect on the leachability and stored energy of the glass. Larger alpha particle doses increase waste glass leachability by less than a factor of two. SRL tests on waste glasses doped with ^{244}Cm and ^{238}Pu to simulate an alpha dose in excess of one million years storage (4×10^{17} α/g) indicated only a doubling in leach rate. Similar results were obtained by PNL for dose rates of 10^{20} α/g.

After 2×10^5 years of storage, approximately 56 L (STP) of helium will have been produced by radionuclide decay in 625 L of waste glass. Assuming helium diffuses through the glass into the 103-L freeboard above the surface, the gas pressure will increase by about 8 psi.

Measurements of glass density indicate a decrease of less than 1% due to alpha irradiation over a similar time period. No increase in glass fracture was observed during the tests.

Groundwater pH

The effect of leachant pH on the rate of borosilicate glass dissolution was measured at SRL at room temperature and 90°C. The studies indicate an optimum pH of 6 to 8.5. Above pH 9 and below pH 5, glass corrosion increases. Most groundwaters from the proposed repositories of brine, basalt, tuff, shale, and granite fall between a pH of 5 to 9.

DWPF CANISTER

Grapple Tong Arrangement

The lifting fixture is specific for the DWPF canister and is described in Figure 13, drawing Y5026Y. At this time, the design is conceptual and may be revised in the future. An alternative concept using an in-cell crane fork and hook is also being evaluated, as shown in Figure 14, drawing W752104. The neck design has been simplified by combining the lifting and grounding flanges into a single flange, thereby shortening and increasing the metal thickness in the neck area. The overall canister length of 9'10" remains unchanged.

Canister Dimensions

Canister dimensions and weight are shown in Figure 15 on the attached drawing SX5-00939, "DWPF Reference Canister-Single Flange."

Principal dimensions and tolerances are:

Overall Length	9 ft 10.0 in. ±0.12 in.
Outside Diameter	24.00 in. ±0.12 in.
Wall Thickness	0.375 in. nominal pipe tolerance
Bow	1/4 in. max.
Surface Finish	125 rms
Inside Volume	26.1 ft^3 nominal
Weight, empty	1000 lb ±5%
Weight, full	4260 lb ±5% (with Frit 131)
Material	304L stainless steel

Material of Construction

Type 304L stainless steel was chosen as the canister material for vitrified waste using the continuous melter process. This recommendation is based on long-term heating tests for up to 20,000 hours (2.3 yr) at temperatures that bracket those expected during interim storage. In these tests, the lifetime of canisters containing vitrified waste glass stored in air was predicted. The thickness of reaction layer observed between the canister alloy and the canister alloy-environment, similar to that expected during interim storage, was extrapolated to estimate the time required for penetration of the 3/8-in.-thick canister.

Data from tests indicate that a 3/8-in.-thick canister of Type 304L stainless steel would not be penetrated for more than 8000 years in a surface facility. By contrast, a 3/8-in.-thick low carbon steel canister would be penetrated by oxidation in about 200 years of storage in a surface facility, and its strength would be reduced in a much shorter period.

Differences in canister lifetime, predicted from these tests, are attributable to the differences in corrosion resistance of the candidate alloys. Both Type 304L stainless steel and low carbon steel react similarly with vitrified waste, but Type 304L stainless steel is much more resistant to both high temperature and atmospheric corrosion in a radiation field than is low carbon steel. The lifetime of canisters constructed from other compositions of austenitic stainless steels would be expected to be similar to Type 304L.

Stainless steel has the additional advantage of forming a relatively thin oxide layer when heated by the molten glass. Tests made at PNL indicate than an inert gas blanket would have to be used with a carbon steel canister to reduce the oxide scale formation to less than 22 lb per canister. Furthermore, the stainless steel surface is much easier to decontaminate by blasting with a frit-water slurry than is carbon steel.

The 0.375-in. nominal wall thickness of a schedule 20, 24-in. stainless steel pipe is adequate for DWPF processing. A theoretical stress analysis was made on the reference canister just after filling with glass at the instantaneous pour rate of 3.8 lb/min. A maximum wall temperature of 427°C and a maximum bottom temperature of 649°C was assumed. The calculations show that the wall is sufficiently thick to pick up the canister immediately after filling, despite the residual shell hoop stress of 32,500 psi caused by the lower coefficient thermal expansion of glass compared to stainless steel. Furthermore, the hoop stress quickly drops to about 5000 psi (at 500°C) due to the glass moving up into the canister void space as it gradually cools. Similarly, the thermal axial stresses were calculated to be 18,900 psi, and the simple static stresses due to weight were 477 psi shear and 177 psi axial. None of these stress levels indicates the need for a wall thickness greater than 3/8 in.

Canister Weight

The reference design canister is filled with approximately 165 gal of glass (22.1 ft^3) to a fill height of 7 ft 7 in. This volume corresponds to a weight of 3260 lb for the current frit (Frit 131) and waste loading, and is about 85% of the available canister volume. The fill volume was chosen based upon operating experience at PNL where about a 15% void is made available in the event of: low density foam partially filling the canister; "roping" of the glass stream causing voids in the frozen melt; and the possibility of spilling glass on the process room floor due to malfunction of load cells, level instrumentation, failure of pouring equipment, operator error, etc.

The current canister design has a single flange with a total inside volume of 26.1 ft^3. The measured glass density of cast synthetic waste glass (Frit 165) is 165 lbs/ft^3. Thus, for 85% fill the glass volume is 22.2 ft^3 corresponding to a total weight of approximately 3660 lbs. The associated fill height is 7'10" measured from the canister base. After operating experience is gained, it may be possible to fill the canister to the top of the straight section of pipe at the intersection of the head with the cylinder. This volume is 25.3 ft^3 corresponding to a glass weight of 4175 lbs and a fill height of 8'8".

Several frit compositions are under evaluation. Until these studies are completed, the reference fill weight is 3,260 lbs.

Internal Pressurization Potential

Internal pressure within the canister is due to accumulation of helium from alpha emissions of transuranic nuclides. A DWPF canister filled with waste glass produces about 0.32 cm^3 of helium per year at 40°C. The helium produced is assumed to diffuse through the glass into the void space above the solid glass surface. At the end of 1000 years, the 103 liter void space pressure has increased by only 0.05 psi. This negligible pressure buildup is of no concern in waste package design. For the case of the single flange canister filled to 25.3 ft^3(733L), the 23 liter void space pressure would increase to 0.2 psi.

Seal Weld

The reference process for sealing the canister is to upset resistance weld a 5-in.-dia, 1/2-in.-thick, 304L stainless steel plug into the canister neck. A force of 100,000 lb, a current of 240,000 amps, and a voltage of approximately 10 volts is used to make the 2-sec weld. The technique was chosen after consideration of seven alternative processes including gas tungsten arc, gas metal arc, plasma arc, Thermit, electron beam, laser beam, and friction welding because of the high weld quality and relatively simple equipment required. Weld tensile strength measurements were made on the upset resistance weld under varying conditions of oxidation to determine the need for machining the throat surface after filling the canister with glass. An upset resistance weld with a 5-in. diameter plug and a machined canister neck was leak-tight to approximately 10^{-8} atm-cm^3/sec for a hydrostatic test pressure of 5,000 psi. If the canister neck is heated to 600°C, but not machined prior to welding, then the weld strength as measured by tensile and hydrostatic tests was reduced by about 20%. However, temperature measurements made on the canister neck during glass filling indicate that the maximum neck temperature does not exceed 300°C, so the canister seal weld is capable of withstanding at least 4,000 psi internal pressure while still maintaining a leak tightness of 1×10^{-8} atm-cm^3/sec.

In the event the canister is used in a repository with a flexible overpack and an open-ended sleeve, the canister could be subjected to relatively high lithostatic or hydrostatic pressures. The maximum pressure in a repository is expected to be less than 18 MPa (2610 psi) which will buckle the 3/8-in canister head above the glass melt surface. To prevent buckling, the head could have supporting ribs welded to the head interior or a thicker spherical head could be used. Modification to the canister head, if required, will be accomplished when repository criteria are determined. Present repository designs use rigid overpacks which are capable of withstanding repository pressures without collapsing.

Canister Decay Heat and Activity

Figure 16 describes the canister decay heat as a function of sludge-only glass from 5 to 1000 years. The canister fill weight for these curves is 3,260 lbs. Figure 17 shows the canister activity for the same period and fill weight.

Figure 18 describes the canister decay heat as a function of sludge-supernate glass for a period of 5 to 1000 years. The starting point is a sludge age of 5 years combined with 15 year-old supernate. Figure 19 shows the canister activity for the same period.

Table 22 describes the above data in tabular form.

Fissionable Material Content

Fissionable material content of a sludge-only glass canister is nominally 950 grams, for a sludge-supernate canister, 785 grams. Distribution of the thermal neutron fissionable nuclides is summarized below:

	Sludge Only Glass		Sludge-Supernate Glass	
	g/lb of Glass	Total g/Canister	g/lb of Glass	Total g/Canister
U-233	6.03E-07	0.002	4.97E-07	0.002
U-235	2.36E-01	769.4	1.95E-01	635.7
Pu-239	5.17E-02	168.5	4.27E-02	139.2
Pu-241	3.81E-03	12.4	3.15E-03	10.3
Total		950.3		785.2

A nuclear criticality safety assessment was made for the glass melter and for storage of canisters in the Interim Storage Facility for both average and abnormally high concentrations of plutonium and U-235. For the glass melter, the worst case was $k_\infty = 0.273$ and for the Interim Storage Building, $k_\infty = 0.110$. For average concentrations of plutonium and U-235, $k_\infty = 0.147$ and $k_\infty = 0.063$ for the two cases. Based upon the above, there is a very large margin of subcriticality for the DWPF glass melter and canisters.

Surface Radiation Dose and Gamma Spectrum

Canister surface radiation dose as a function of distance for a reference canister filled with sludge-only glass is described in Table 22 for two cases of glass density. The source terms for these cases is shown in Table 23.

Table 24 describes canister surface radiation dose for a reference canister filled with sludge-supernate glass for two different glass densities (Cases III and IV) as well as one case (Case V) of high density glass, 35% waste loading and a fill height of 107 in. Case III with a surface dose rate of 5500 rem/hr is the reference case and current design basis. Case V represents a case of practical upper limit with respect to glass waste loading, glass density, and canister fill height. The source terms for Cases III, IV, and V are described in Table 25.

Canister Surface Contamination

The criteria selected for canister surface contamination levels are identical to those specified for Department of Transportation shipping limits and are useful guides for canister decontamination by the frit-water slurry blasting technique. Canisters decontaminated to these levels are not expected to significantly contribute to air contamination within the Interim Storage Building. The canister surface contamination limits selected are:

Alpha	220 dis/min/100 cm^2
Beta-Gamma	2200 dis/min/100 cm^2

Labeling

Each canister will have a number stamped on the horizontal and vertical faces of the upper flange. The numbers will be approximately 1-in. high and will be visible by television viewing. Each number will identify the canister fabrication and processing history.

Canister Temperature

Table 27 describes temperature of a canister containing a sludge-supernate waste form at power levels of 425-1000 watts, when in air at temperatures of 20°C and 38°C. Surface temperature of the 470 watt canisters is estimated to be 45°C.

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TABLES

TABLE 1

Chemical Composition of Sludge Feed (dry basis)

Soluble Solids

Species	Wt %
Group 1 √	
$NaNO_3$	2.89E+1
$NaNO_2$	1.17E+1
$NaAlO_2$	1.61E+1
NaOH	3.16E+1
Na_2CO_3	4.88
Na_2SO_4	6.54
NaCl	1.98E-1
NaF	1.28E-2
Na[HgO(OH)]	3.97E-2
Group 2 √√	
Group A*	8.26E-4
Group B**	2.37E-4
$Na_2PuO_2(OH)_4$	1.61E-6
$UO_2(OH)_2$	1.15E-4
Na_2RuO_4	3.23E-3
Na_2RhO_4	3.31E-4
$CsNO_3$	6.18E-3
$Ba(NO_3)_2$	1.04E-5
$Sr(NO_3)_2$	9.28E-6
$Y(NO_3)_3$	6.59E-6
NaI	1.86E-5

Insoluble Solids

Species	Wt %
Group 1	
$Fe(OH)_3$	3.81E+1
$Al(OH)_3$	1.57E+1
MnO_2	6.42
$Ni(OH)_2$	2.42
$CaCO_3$	5.00
Zeolite***	4.60
SiO_2	7.34
NaOH	4.10
$NaNO_3$	3.53
HgO	1.99
$CaSO_4$	5.93E-1
CaC_2O_4	5.05E-1
$Ca_3(PO_4)_2$	4.67E-1
CaF_2	1.26E-1
NaCl	1.26E-1
ThO_2	7.19E-1

Insoluble Solids

Species	Wt %
Group 1	
$PbSO_4$	1.76E-1
$Cr(OH)_3$	4.80E-1
AgOH	2.52E-2
$Cu(OH)_2$	1.39E-1
$Co(OH)_3$	7.57E-2
$Zn(OH)_2$	3.66E-1
$Mg(OH)_2$	6.31E-1
C	1.26E-1
Group 2	
Group A**	3.42E-1
Group B	1.12
PuO_2	4.58E-2
$SrCO_3$	1.31E-1
$Y_2(CO_3)_3$	8.63E-2
RuO_2	8.25E-2
RhO_2	1.75E-2
$CsNO_3$	1.32E-2
$BaSO_4$	1.87E-1
$UO_2(OH)_2$	4.24
NaI	1.26E-2

* Tc, Se, Te, Rb, Mo.

** Ag, Cd, Cr, Pd, Tl, La, Ce, Pr, Pm, Nd, Sm, Tb, Sn, Sb, Co, Zr, Nb, Eu, Np, Am, Cm.

√ Group 1: Calculated from analyses of actual waste currently in storage.

√√ Group 2: Fission products and actinide isotopes calculated from partition between insoluble and soluble fractions of the waste blend.

*** See Table 21 for Zeolite composition.

TABLE 2

Radionuclide Content of Sludge Feed

Isotope	Ci/gal	Isotope	Ci/gal	Isotope	Ci/gal
^{3}H	5.27E-05	^{124}Sb	9.12E-11	^{155}Eu	6.08E-01
^{14}C	1.58E-06	^{125}Sb	1.06E+00	^{160}Tb	1.43E-09
^{51}Cr	1.13E-19	^{126}Sb	2.69E-06	^{208}Ti	1.34E-06
^{60}Co	2.18E-01	^{126m}Sb	1.92E-04	^{232}U	1.86E-04
^{59}Ni	2.53E-03	^{125m}Te	1.93E-01	^{233}U	2.22E-08
^{63}Ni	3.14E-01	^{127}Te	8.41E-05	^{234}U	5.86E-04
^{79}Se	1.32E-04	^{127m}Te	8.58E-05	^{235}U	1.95E-06
^{87}Rb	8.75E-09	^{129}Te	2.14E-15	^{236}U	4.24E-05
^{89}Sr	9.83E-08	^{129m}Te	3.32E-15	^{238}U	1.08E-05
^{90}Sr	5.58E+01	^{129}I	1.69E-08	^{236}Np	2.22E-11
^{90}Y	3.39E+01	^{134}Cs	2.33E-01	^{237}Np	1.13E-05
^{91}Y	1.05E-06	^{135}Cs	4.07E-06	^{236}Pu	1.07E-04
^{93}Zr	1.44E-03	^{137}Cs	2.20E+00	^{237}Pu	7.83E-15
^{95}Zr	1.29E-05	^{137m}Ba	2.08E+00	^{238}Pu	1.30E+00
^{94}Nb	1.20E-06	^{141}Ce	4.58E-14	^{239}Pu	1.22E-02
^{95}Nb	2.72E-05	^{142}Ce	1.22E-08	^{240}Pu	7.76E-03
^{95m}Nb	1.59E-07	^{144}Ce	1.26E+01	^{241}Pu	1.47E+00
^{99}Tc	2.39E-03	^{144}Pr	1.26E+01	^{242}Pu	1.07E-05
^{103}Ru	2.62E-11	^{144m}Pr	1.51E-01	^{241}Am	1.38E-02
^{106}Ru	3.49E+00	^{144}Nd	6.14E-13	^{242}Am	1.82E-05
^{103m}Rh	2.35E-11	^{147}Pm	3.07E+01	^{242m}Am	1.83E-05
^{106}Rh	3.16E+00	^{148}Pm	8.85E-14	^{243}Am	7.33E-06
^{107}Pd	1.22E-05	^{148m}Pm	1.28E-12	^{242}Cm	4.46E-05
^{110m}Ag	1.86E-02	^{147}Sm	2.50E-09	^{243}Cm	7.06E-06
^{113}Cd	1.12E-17	^{148}Sm	7.24E-15	^{244}Cm	2.07E-04
^{115m}Cd	2.71E-13	^{149}Sm	2.23E-15	^{245}Cm	8.46E-09
^{121m}Sn	3.80E-05	^{151}Sm	3.11E-01	^{246}Cm	6.75E-10
^{123}Sn	3.37E-04	^{152}Eu	4.72E-03	^{247}Cm	8.30E-16
^{126}Sn	1.91E-04	^{154}Eu	7.94E-01	^{248}Cm	8.67E-16

Total Activity 1.63E+02 Ci/gal
Decay Heat
  Total Primary 4.37E-01 watt/gal
  Total Gammas 2.94E-02 watt/gal

TABLE 3

Isotopic Content of Sludge Feed

ISOTOPE	GM/GAL	ISOTOPE	GM/GAL	ISOTOPE	GM/GAL
H 3	5.49E-09	Ru104	1.25E-01	Te125M	1.07E-05
C 14	3.54E-07	Ru106	1.04E-03	Te126	9.37E-05
Cr 51	1.23E-24	Rh103	1.28E-01	Te127	8.19E-11
Co 60	1.93E-04	Rh103M	7.22E-19	Te127M	9.09E-09
Ni 59	3.13E-02	Rh106	8.87E-10	Te128	2.57E-02
Ni 63	5.32E-03	Pd104	9.74E-03	Te129	1.02E-22
Se 77	3.05E-04	Pd105	7.66E-02	Te129M	1.10E-19
Se 78	7.65E-04	Pd106	4.90E-02	Te130	9.28E-02
Se 79	1.89E-03	Pd107	2.37E-02	I 127	2.26E-05
Se 80	4.50E-03	Pd108	1.38E-02	I 129	9.58E-05
Se 82	9.09E-03	Pd110	4.72E-03	Cs133	2.80E-02
Rb 85	4.08E-02	Ag109	8.45E-03	Cs134	1.80E-04
Rb 87	1.00E-01	Ag110M	3.92E-06	Cs135	3.53E-03
Sr 88	2.78E-01	Cd110	1.48E-04	Cs137	2.54E-02
Sr 89	3.38E-12	Cd111	6.97E-04	Ba134	3.55E-02
Sr 90	4.09E-01	Cd112	4.81E-04	Ba136	3.76E-03
Y 89	2.20E-01	Cd113	3.29E-05	Ba137	1.44E-01
Y 90	6.22E-05	Cd114	7.84E-04	Ba137M	8.87E-09
Y 91	4.29E-11	Cd115M	1.06E-17	Ba138	1.28E+00
Zr 90	4.03E-02	Cd116	3.62E-04	La139	5.45E-01
Zr 91	8.21E-01	Sn116	3.12E-04	Ce140	5.38E-01
Zr 92	3.29E-01	Sn117	1.61E-03	Ce141	1.61E-18
Zr 93	5.72E-01	Sn118	1.73E-03	Ce142	5.06E-01
Zr 94	3.65E-01	Sn119	1.69E-03	Ce144	8.93E-03
Zr 95	6.02E-10	Sn120	1.75E-03	Pr141	5.04E-01
Zr 96	3.67E-01	Sn121M	7.07E-07	Pr144	1.66E-07
Nb 94	6.37E-06	Sn122	1.95E-03	Pr144M	8.34E-10
Nb 95	6.93E-10	Sn123	4.10E-08	Nd142	1.79E-03
Nb 95M	4.20E-13	Sn124	2.93E-03	Nd143	6.01E-01
Mo 95	2.84E-01	Sn126	6.73E-03	Nd144	5.17E-01
Mo 96	1.16E-03	Sb121	1.82E-03	Nd145	3.33E-01
Mo 97	2.72E-01	Sb123	2.81E-03	Nd146	2.70E-01
Mo 98	2.74E-01	Sb124	5.21E-15	Nd148	1.56E-01
Mo100	3.00E-01	Sb125	1.03E-03	Nd150	6.26E-02
Tc 99	1.41E-01	Sb126	3.22E-11	Pm147	3.31E-02
Ru100	2.92E-03	Sb126M	2.45E-12	Pm148	5.38E-19
Ru101	2.81E-01	Te122	2.03E-05	Pm148M	6.00E-17
Ru102	2.49E-01	Te124	9.43E-06	Sm147	1.07E-01
Ru103	8.12E-16	Te125	2.15E-03	Sm148	2.37E-02

TABLE 3

Isotopic Content of Sludge Feed

ISOTOPE	GM/GAL	ISOTOPE	GM/GAL	ISOTOPE	GM/GAL
Sm149	9.27E-03	Tl208	4.55E-15	Pu240	8.41E-02
Sm150	1.31E-01	Tl209	1.34E-23	Pu241	1.45E-02
Sm151	1.18E-02	U 232	8.67E-06	Pu242	2.73E-03
Sm152	4.74E-02	U 233	2.30E-06	Am241	4.01E-03
Sm154	8.40E-03	U 234	9.38E-02	Am242	2.25E-11
Eu151	4.97E-04	U 235	9.01E-01	Am242M	1.88E-06
Eu152	2.67E-05	U 236	6.56E-01	Am243	3.68E-05
Eu153	2.63E-02	U 238	3.23E+01	Cm242	1.35E-08
Eu154	2.94E-03	Np236	1.69E-09	Cm243	1.37E-07
Eu155	1.31E-03	Np237	1.60E-02	Cm244	2.56E-06
Tb159	2.61E-04	Pu236	2.01E-07	Cm245	4.91E-08
Tb160	1.27E-13	Pu237	6.49E-19	Cm246	2.20E-09
Tl206	2.65E-29	Pu238	7.58E-02	Cm247	8.94E-12
Tl207	6.53E-19	Pu239	1.97E-01	Cm248	2.04E-13

Total 4.57E+01 GM/GAL

TABLE 4

Chemical Composition of Sludge-Only Glass

Component	Wt %	Component	Wt %
Ag_2O	0.9039E-02	MnO	2.082
Al_2O_3	4.057	$Na_2B_4O_7$	0.1750E-03
B_2O_3	10.42	Na_2O	14.69
BaO	0.4747E-01	NiO	0.7535
$Ca_3(PO_4)_2$	0.1801	PbO	0.5006E-01
CaO	1.295	PuO_2	0.1771E-01
CoO	0.1992E-01	RhO_2	0.6768E-02
Cr_2O_3	0.1362	RuO_2	0.2983E-01
Cs_2O	0.3524E-02	SiO_2	44.10
CuO	0.4381E-01	SrO	0.3555E-01
Fe_2O_3	8.298	ThO_2	0.2776
FeO	2.443	TiO_2	0.7101
Group A*	0.1289	UO_2	1.456
Group B**	0.4330	Y_2O_3	0.2105E-01
K_2O	0.1854E-03	Zeolite	1.774
La_2O_3	0.3550	ZnO	0.1155
Li_2O	4.061	ZrO_2	0.3550
MgO	1.592		

* Tc, Se,Te, Rb, Mo.

** Ag, Cd, Cr, Pd, Tl, La, Ce, Pr,Pm, Nd, Sm, Tb, Sn, Sb,Co, Zr, Nb, Eu, Np, Am, Cm.

TABLE 5

Radionuclide Content of Sludge-Only Glass

Isotope	Ci/lb	Isotope	Ci/lb	Isotope	Ci/lb
^{51}Cr	2.98E-20	^{125}Sb	2.78E-01	^{160}Tb	3.76E-10
^{60}Co	5.72E-02	^{126}Sb	7.07E-07	^{208}Ti	3.52E-07
^{59}Ni	6.64E-04	^{126m}Sb	5.05E-05	^{232}U	4.89E-05
^{63}Ni	8.25E-02	^{125m}Te	5.05E-02	^{233}U	5.81E-09
^{79}Se	3.45E-05	^{127}Te	2.21E-05	^{234}U	1.54E-04
^{87}Rb	2.30E-09	^{127m}Te	2.25E-05	^{235}U	5.11E-07
^{89}Sr	2.58E-08	^{129}Te	5.60E-16	^{236}U	1.11E-05
^{90}Sr	1.47E+01	^{129m}Te	8.72E-16	^{238}U	2.85E-06
^{90}Y	8.91E+00	^{134}Cs	5.46E-02	^{236}Np	5.83E-12
^{91}Y	2.77E-07	^{135}Cs	9.51E-07	^{237}Np	2.96E-06
^{93}Zr	3.77E-04	^{137}Cs	5.15E-01	^{236}Pu	2.80E-05
^{95}Zr	3.38E-06	^{137m}Ba	4.87E-01	^{237}Pu	2.05E-15
^{94}Nb	3.14E-07	^{141}Ce	1.20E-14	^{238}Pu	3.40E-01
^{95}Nb	7.13E-06	^{142}Ce	3.19E-09	^{239}Pu	3.21E-03
^{95m}Nb	4.18E-08	^{144}Ce	3.29E+00	^{240}Pu	2.04E-03
^{99}Tc	6.29E-04	^{144}Pr	3.29E+00	^{241}Pu	3.85E-01
^{103}Ru	6.88E-12	^{144m}Pr	3.97E-02	^{242}Pu	2.81E-06
^{106}Ru	9.15E-01	^{144}Nd	1.61E-13	^{241}Am	3.61E-03
^{103m}Rh	6.17E-12	^{147}Pm	8.07E+00	^{242}Am	4.77E-06
^{106}Rh	8.29E-01	^{148}Pm	2.32E-14	^{242m}Am	4.80E-06
^{107}Pd	3.13E-06	^{148m}Pm	3.37E-13	^{243}Am	1.92E-06
^{110m}Ag	4.59E-03	^{147}Sm	6.56E-10	^{242}Cm	1.17E-05
^{113}Cd	2.94E-18	^{148}Sm	1.90E-15	^{243}Cm	1.85E-06
^{115m}Cd	7.10E-14	^{149}Sm	5.84E-16	^{244}Cm	5.44E-05
^{121m}Sn	9.97E-06	^{151}Sm	8.15E-02	^{245}Cm	2.22E-09
^{123}Sn	8.85E-05	^{152}Eu	1.24E-03	^{246}Cm	1.77E-10
^{126}Sn	5.02E-05	^{154}Eu	2.08E-01	^{247}Cm	2.18E-16
^{124}Sb	2.39E-11	^{155}Eu	1.60E-01	^{248}Cm	2.27E-16

Total Activity 4.27E+1 Ci/lb

Decay Heat

Total Primary 1.15E-01 watts/lb

Total Gammas 7.43E-03 watts/lb

TABLE 6

Isotopic Content of Sludge-Only Glass

ISOTOPE	GMS/LB	ISOTOPE	GMS/LB	ISOTOPE	GMS/LB
Cr 51	3.22E-25	Rh103	3.37E-02	Te127	8.36E-12
Co 60	5.05E-05	Rh103M	1.89E-19	Te127M	2.39E-09
Ni 59	8.22E-03	Rh106	2.33E-10	Te128	6.74E-03
Ni 63	1.40E-03	Pd104	2.50E-03	Te129	2.67E-23
Se 77	7.99E-05	Pd105	1.97E-02	Te129M	2.89E-20
Se 78	2.01E-04	Pd106	1.26E-02	Te130	2.43E-02
Se 79	4.95E-04	Pd107	6.08E-03	Cs133	6..54E-03
Se 80	1.18E-03	Pd108	3.54E-03	Cs134	4.21E-05
Se 82	2.38E-03	Pd110	1.21E-03	Cs135	8.25E-04
Rb 85	1.07E-02	Ag109	2.08E-03	Cs137	5.95E-03
Rb 87	2.62E-02	Ag110M	9.66E-07	Ba134	9.32E-03
Sr 88	7.29E-02	Cd110	3.88E-05	Ba136	9.87E-04
Sr 89	8.86E-13	Cd111	1.83E-04	Ba137	3.79E-02
Sr 90	1.07E-01	Cd112	1.26E-04	Ba137M	9.05E-10
Y 89	5.78E-02	Cd113	8.64E-06	Ba138	3.37E-01
Y 90	1.64E-05	Cd114	2.06E-04	La139	1.43E-01
Y 91	1.13E-11	Cd115M	2.79E-18	Ce140	1.41E-01
Zr 90	1.06E-02	Cd116	9.49E-05	Ce141	4.22E-19
Zr 91	8.41E-02	Sn116	8.19E-05	Ce142	1.33E-01
Zr 92	8.62E-02	Sn117	4.23E-04	Ce144	1.03E-03
Zr 93	1.50E-01	Sn118	4.55E-04	Pr141	1.32E-01
Zr 94	9.59E-02	Sn119	4.43E-04	Pr144	4.36E-08
Zr 95	1.58E-10	Sn120	4.59E-04	Pr144M	2.19E-10
Zr 96	9.62E-02	Sn121M	1.85E-07	Nd142	4.71E-04
Nb 94	1.67E-06	Sn122	5.12E-04	Nd143	1.58E-01
Nb 95	1.82E-10	Sn123	1.08E-08	Nd144	1.36E-01
Nb 95M	1.10E-13	Sn124	7.68E-04	Nd145	8.73E-02
Mo 95	7.46E-02	Sn126	1.77E-03	Nd146	7.09E-02
Mo 96	3.03E-04	Sb121	4.77E-04	Nd148	4.09E-02
Mo 97	7.14E-02	Sb123	6.05E-04	Nd150	1.64E-02
Mo 98	7.20E-02	Sb124	1.37E-15	Pm147	8.70E-03
Mo100	7.87E-02	Sb125	2.69E-04	Pm148	1.41E-19
Tc 99	3.71E-02	Sb126	8.45E-12	Pm148M	1.57E-17
Ru100	7.65E-04	Sb126M	6.42E-13	Sm147	2.82E-02
Ru101	7.38E-02	Te122	5.31E-06	Sm148	6.23E-03
Ru102	6.52E-02	Te124	2.47E-06	Sm149	2.43E-03
Ru103	2.13E-16	Te125	5.64E-04	Sm150	3.45E-02
Ru104	3.28E-02	Te125M	2.80E-06	Sm151	3.10E-03
Ru106	2.73E-04	Te126	2.46E-05	Sm152	1.24E-02

TABLE 6

Isotopic Content of Sludge-Only Glass

ISOTOPE	GMS/LB	ISOTOPE	GMS/LB	ISOTOPE	GMS/LB
Sm154	2.20E-03	U 233	6.03E-07	Pu242	7.17E-04
Eu151	1.30E-04	U 234	2.46E-02	Am241	1.05E-03
Eu152	7.02E-06	U 235	2.36E-01	Am242	5.90E-12
Eu153	6.90E-03	U 236	1.72E-01	Am242M	4.94E-07
Eu154	7.72E-04	U 238	8.47E+00	Am243	9.65E-06
Eu155	3.43E-04	Np236	4.43E-10	Cm242	3.54E-09
Tb159	6.84E-05	Np237	4.20E-03	Cm243	3.59E-08
Tb160	3.33E-14	Pu236	5.28E-08	Cm244	6.72E-07
Tl206	6.95E-30	Pu237	1.70E-19	Cm245	1.29E-08
Tl207	1.71E-19	Pu238	1.99E-02	Cm246	5.76E-10
Tl208	1.19E-15	Pu239	5.17E-02	Cm247	2.35E-12
Tl209	3.52E-24	Pu240	8.96E-03	Cm248	5.36E-14
U 232	2.27E-06	Pu241	3.81E-03		

Total 1.20E+01 GMS/LB

TABLE 7

Chemical Composition of Supernate Feed (dry basis)

Soluble Solids, wt %		Insoluble Solids, wt %	
$NaNO_3$	40.3	$Al(OH)_3$	33.1
NaOH	17.0	$Fe(OH)_3$	30.2
$NaNO_2$	16.3	SiO_2	5.84
$NaAlO_2$	9.74	MnO_2	5.14
Na_2SO_4	9.12	$CaCO_3$	3.98
Na_2CO_3	6.80	Zeolite***	3.69
$Na_2C_2O_4$	4.37E-1	$NaNO_3$	2.81
NaCl	2.76E-1	NaOH	3.27
Na[HgO(OH)]	5.53E-2	$Ni(OH)_2$	1.94
NaF	1.79E-2	HgO	1.58
$CsNO_3$	7.76E-3	ThO_2	5.72E-1
Na_2RuO_4	4.52E-3	$Mg(OH)_2$	5.04E-1
Group A*	1.15E-3	$CaSO_4$	4.75E-1
Na_2RhO_4	9.54E-4	CaC_2O_4	3.98E-1
Group B**	3.31E-4	$Cr(OH)_3$	3.78E-1
$UO_2(OH)_2$	1.47E-4	$Ca_3(PO_4)_2$	3.69E-1
NaI	2.57E-5	$Zn(OH)_2$	2.90E-1
$Ba(NO_3)_2$	1.67E-5	$PbSO_4$	1.35E-1
$Sr(NO_3)_2$	1.12E-5	$Cu(OH)_2$	1.06E-1
$Y(NO_3)_3$	5.58E-6	CaF_2	9.69E-2

* Radionuclides of Mo, Rb, Se, Tc, Te

** Radionuclides of Ag, Am, Cd, Ce, Cm, Co, Cr, Eu, La, Nb, Nd, Np, Pd, Pm, Pr, Sb, Sm, Sn, Tb, Tl, Zr

*** See Table 21 for Zeolite composition

TABLE 7, Contd

Soluble Solids, wt %		Insoluble Solids, wt %	
$Na_2PuO_2(OH)_4$	2.16E-6	NaCl	9.69E-2
		C	9.69E-2
		$Co(OH)_3$	5.82E-2
		AgOH	1.94E-2
		$UO_2(OH)_2$	3.37
		Group B*	9.01E-1
		Group A**	2.72E-1
		$SrCO_3$	8.98E-2
		$Y_2(CO_3)_3$	6.86E-2
		RuO_2	6.55E-2
		PuO_2	3.54E-2
		$BaSO_4$	1.72E-2
		RhO_2	1.39E-2
		NaI	1.12E-2
		$CsNO_3$	9.41E-3

* Radionuclides of Mo, Rb, Se, Tc, Te

** Radionuclides of Ag, Am, Cd, Ce, Cm, Co, Cr, Eu, La, Nb, Nd, Np, Pd, Pm, Pr, Sb, Sm, Sn, Tb, Tl, Zr

TABLE 8

Radionuclide Content of Feed from Supernate Process

Isotope	Ci/gal	Isotope	Ci/gal	Isotope	Ci/gal
^{3}H	6.03E-05	^{137}Cs	2.37E+02	^{239}Pu	1.23E-04
^{89}Sr	8.24E-10	^{137m}Ba	2.24E+02	^{240}Pu	7.79E-05
^{90}Sr	4.68E-01	^{236}Pu	1.07E-06	^{241}Pu	1.47E-02
^{134}Cs	2.45E+00	^{237}Pu	7.86E-17	^{242}Pu	1.08E-07
^{135}Cs	5.44E-04	^{238}Pu	1.30E-02		

Total Activity 4.64E+02 Ci/gal
Decay Heat
Total Primary 2.65E-01 watt/gal
Total Gammas 8.16E-01 watt/gal

TABLE 9

Isotopic Content of Feed from Supernate Process

ISOTOPE	GM/GAL	ISOTOPE	GM/GAL	ISOTOPE	GM/GAL
H 3	6.28E-09	Cs135	4.72E-01	Pu238	7.61E-04
Sr 88	2.33E-03	Cs137	2.73E+00	Pu239	1.98E-03
Sr 89	2.83E-14	Ba137M	4.16E-07	Pu240	3.43E-04
Sr 90	3.43E-03	Pu236	2.02E-09	Pu241	1.46E-04
Cs133	3.74E+00	Pu237	6.51E-21	Pu242	2.74E-05
Cs134	1.89E-03				

Total 6.96E+00 GM/GAL

TABLE 10

Chemical Composition of Sludge-Supernate Glass

Component	wt %	Component	wt %
Ag_2O	0.75E-02	MnO	1.73
Al_2O_3	3.35	$Na_2B_4O_7$	0.21E-03
B_2O_3	10.59	Na_2O	17.59
BaO	0.39E-01	NiO	0.62
$Ca_3(PO_4)_2$	0.15	PbO	0.41E-01
CaO	1.07	PuO_2	0.15E-01
CoO	0.16E-01	RhO_2	0.56E-02
Cr_2O_3	0.11	RuO_2	0.25E-01
Cs_2O	0.73E-01	SiO_2	45.09
CuO	0.36E-01	SrO	0.29E-01
Fe_2O_3	6.09	ThO_2	0.23
FeO	2.70	TiO_2	0.72
Group A*	0.11	UO_2	1.20
Group B**	0.36	Y_2O_3	0.17E-01
K_2O	0.19E-03	Zeolite	1.47
La_2O_3	0.36	ZnO	0.95E-01
Li_2O	4.13	ZrO_2	0.36
MgO	1.59		

* Group A: Radionuclides of Mo, Rb, Se, Tc, Te

** Group B: Radionuclides of Ag, Am, Cd, Ce, Cm, Co, Cr, Eu, La, Nb, Nd, Np, Pd, Pm, Pr, Sb, Sm, Sn, Tb, Tl, Zr

TABLE 11

Radionuclide Content of Sludge-Supernate Glass

Isotope	Ci/lb	Isotope	Ci/lb	Isotope	Ci/lb
^{51}Cr	2.45E-20	^{125}Sb	2.29E-01	^{160}Tb	3.09E-10
^{60}Co	4.72E-02	^{126}Sb	5.83E-07	^{208}Ti	2.90E-07
^{59}Ni	5.48E-04	^{126m}Sb	4.16E-05	^{232}U	4.03E-05
^{63}Ni	6.80E-02	^{125m}Te	4.16E-02	^{233}U	4.79E-09
^{79}Se	2.84E-05	^{127}Te	1.82E-05	^{234}U	1.27E-04
^{87}Rb	1.89E-09	^{127m}Te	1.86E-05	^{235}U	4.21E-07
^{89}Sr	2.13E-08	^{129}Te	4.62E-16	^{236}U	9.18E-06
^{90}Sr	1.21E+01	^{129m}Te	7.19E-16	^{238}U	2.35E-06
^{90}Y	7.35E+00	^{134}Cs	1.05E-01	^{236}Np	4.81E-12
^{91}Y	2.28E-07	^{135}Cs	2.33E-05	^{237}Np	2.44E-06
^{93}Zr	3.11E-04	^{137}Cs	1.01E+01	^{236}Pu	2.32E-05
^{95}Zr	2.79E-06	^{137m}Ba	9.60E+00	^{237}Pu	1.70E-15
^{94}Nb	2.58E-07	^{141}Ce	9.91E-15	^{238}Pu	2.81E-01
^{95}Nb	5.88E-06	^{142}Ce	2.63E-09	^{239}Pu	2.65E-03
^{95m}Nb	3.45E-08	^{144}Ce	2.71E+00	^{240}Pu	1.68E-03
^{99}Tc	5.18E-04	^{144}Pr	2.71E+00	^{241}Pu	3.18E-01
^{103}Ru	5.67E-12	^{144m}Pr	3.27E-02	^{242}Pu	2.32E-06
^{106}Ru	7.54E-01	^{144}Nd	1.33E-13	^{241}Am	2.98E-03
^{103m}Rh	5.08E-12	^{147}Pm	6.65E+00	^{242}Am	3.93E-06
^{106}Rh	6.84E-01	^{148}Pm	1.91E-14	^{242m}Am	3.96E-06
^{107}Pd	2.58E-06	^{148m}Pm	2.77E-13	^{243}Am	1.58E-06
^{110m}Ag	3.78E-03	^{147}Sm	5.40E-10	^{242}Cm	9.65E-06
^{113}Cd	2.42E-18	^{148}Sm	1.57E-15	^{243}Cm	1.53E-06
^{115m}Cd	5.85E-14	^{149}Sm	4.82E-16	^{244}Cm	4.48E-05
^{121m}Sn	8.22E-06	^{151}Sm	6.72E-02	^{245}Cm	1.83E-09
^{123}Sn	7.29E-05	^{152}Eu	1.02E-03	^{246}Cm	1.46E-10
^{126}Sn	4.14E-05	^{154}Eu	1.72E-01	^{247}Cm	1.79E-16
^{124}Sb	1.97E-11	^{155}Eu	1.32E-01	^{248}Cm	1.87E-16

Total Activity	5.42E+01 Ci/lb
Decay Heat	
Total Primary	1.05E-01 watts/lb
Total Gammas	3.93E-02 watts/lb

TABLE 12

Isotopic Content of Sludge-Supernate Glass

ISOTOPE	GMS/LB	ISOTOPE	GMS/LB	ISOTOPE	GMS/LB
Cr 51	2.66E-25	Rh103	2.78E-02	Te127	6.89E-12
Co 60	4.17E-05	Rh103M	1.56E-19	Te127M	1.97E-09
Ni 59	6.77E-03	Rh106	1.92E-10	Te128	5.55E-03
Ni 63	1.15E-03	Pd104	2.06E-03	Te129	2.20E-23
Se 77	6.58E-05	Pd105	1.62E-02	Te129M	2.38E-20
Se 78	1.65E-04	Pd106	1.04E-02	Te130	2.01E-02
Se 79	4.08E-04	Pd107	5.01E-03	Cs133	1.60E-01
Se 80	9.73E-04	Pd108	2.92E-03	Cs134	8.12E-05
Se 82	1.97E-03	Pd110	9.98E-04	Cs135	2.02E-02
Rb 85	8.82E-03	Ag109	1.71E-03	Cs137	1.17E-01
Rb 87	2.16E-02	Ag110M	7.96E-07	Ba134	7.68E-03
Sr 88	6.02E-02	Cd110	8.19E-05	Ba136	8.14E-04
Sr 89	7.32E-13	Cd111	1.51E-04	Ba137	3.12E-02
Sr 90	8.86E-02	Cd112	1.04E-04	Ba137M	1.78E-08
Y 89	4.76E-02	Cd113	7.12E-06	Ba138	2.78E-01
Y 90	1.35E-05	Cd114	1.69E-04	La139	1.18E-01
Y 91	9.30E-12	Cd115M	2.30E-18	Ce140	1.16E-01
Zr 90	8.72E-03	Cd116	7.82E-05	Ce141	3.48E-19
Zr 91	6.93E-02	Sn116	6.75E-05	Ce142	1.09E-01
Zr 92	7.11E-02	Sn117	3.49E-04	Ce144	8.51E-04
Zr 93	1.24E-01	Sn118	3.75E-04	Pr141	1.09E-01
Zr 94	7.90E-02	Sn119	3.65E-04	Pr144	3.59E-08
Zr 95	1.30E-10	Sn120	3.78E-04	Pr144M	1.80E-10
Zr 96	7.93E-02	Sn121M	1.53E-07	Nd142	3.88E-04
Nb 94	1.38E-06	Sn122	4.22E-04	Nd143	1.30E-01
Nb 95	1.50E-10	Sn123	8.87E-09	Nd144	1.12E-01
Nb 95M	9.08E-14	Sn124	6.33E-04	Nd145	7.20E-02
Mo 95	6.15E-02	Sn126	1.46E-03	Nd146	5.84E-02
Mo 96	2.50E-04	Sb121	3.94E-04	Nd148	3.37E-02
Mo 97	5.88E-02	Sb123	4.99E-04	Nd150	1.35E-02
Mo 98	5.93E-02	Sb124	1.13E-15	Pm147	7.17E-03
Mo100	6.48E-02	Sb125	2.22E-04	Pm148	1.16E-19
Tc 99	3.05E-02	Sb126	6.97E-12	Pm148M	1.30E-17
Ru100	6.30E-04	Sb126M	5.29E-13	Sm147	2.32E-02
Ru101	6.08E-02	Te122	4.38E-06	Sm148	5.13E-03
Ru102	5.37E-02	Te124	2.04E-06	Sm149	2.00E-03
Ru103	1.76E-16	Te125	4.65E-04	Sm150	2.84E-02
Ru104	2.70E-02	Te125M	2.31E-06	Sm151	2.55E-03
Ru106	2.25E-04	Te126	2.03E-05	Sm152	1.02E-02

TABLE 12

Isotopic Content of Sludge-Supernate Glass

ISOTOPE	GMS/LB	ISOTOPE	GMS/LB	ISOTOPE	GMS/LB
Sm154	1.82E-03	U 233	4.97E-07	Pu242	5.92E-04
Eu151	1.07E-04	U 234	2.03E-02	Am241	8.67E-04
Eu152	5.78E-06	U 235	1.95E-01	Am242	4.86E-12
Eu153	5.68E-03	U 236	1.42E-01	Am242M	4.07E-07
Eu154	6.36E-04	U 238	6.98E+00	Am243	7.95E-06
Eu155	2.83E-04	Np236	3.65E-10	Cm242	2.92E-09
Tb159	5.64E-05	Np237	8.46E-03	Cm243	2.96E-08
Tb160	2.74E-14	Pu236	4.36E-08	Cm244	5.54E-07
Tl206	5.73E-30	Pu237	1.41E-19	Cm245	1.06E-08
Tl207	1.41E-19	Pu238	1.64E-02	Cm246	4.75E-10
Tl208	9.84E-16	Pu239	4.27E-02	Cm247	1.93E-12
Tl209	2.90E-24	Pu240	7.40E-03	Cm248	4.42E-14
U 232	1.87E-06	Pu241	3.15E-03		

Total 1.02E+01 GMS/LB

TABLE 13

Chemical Compositions of Glass Frits

Oxide	Weight Percent			
	Frit Number			
	18	21*	131**	165
SiO_2	52.5	52.5	57.9	68.0
Na_2O	22.5	18.5	17.7	13.0
TiO_2	10.0	10.0	1.0	-
B_2O_3	10.0	10.0	14.7	10.0
Li_2O	-	4.0	5.7	7.0
MgO	-	-	2.0	1.0
ZrO_2	-	-	0.5	1.0
La_2O_3	-	-	0.5	-
CaO	5.0	5.0	-	-

* Frit used in leachability tests for Figures 9 to 12.

** Current reference frit is Frit 131.

TABLE 14

Physical Properties of Glass Waste Forms

Property	Value
Thermal Conductivity at 100°C	0.55 Btu/(hr)(ft)(°F)
Heat Capacity at 100°C	0.22 cal/(g)(°C)
Fractional Thermal Expansion*	1.22×10^{-5}/°C
Young's Modulus**	9×10^6 psi
Tensile Strength	9×10^3 psi
Compressive Strength	1×10^5 psi
Poisson's Ratio†	0.2
Density at 100°C*	2.75 g/cc
Softening Point*	502°C

* Experimentally determined for Frit 131 glasses.

** Young's modulus, or the modulus of elasticity, measures the stiffness of the material

† Poisson's ratio is equivalent to the ratio of equatorial to axial strain under an applied axial stress.

TABLE 15

Composition of Simulated SRP Waste Glass

Component	Composite %	High-Al %	High-Fe %
Fe_2O_3	47.3	13.8	59.1
MnO_2	13.6	11.3	4.0
Zeolite**	10.2	10.2	9.7
Al_2O_3	9.5	49.3	1.4
NiO	5.8	2.0	10.1
SiO_2	4.1	4.5	2.9
CaO	3.5	0.9	4.0
Na_2O	3.1	5.0	5.9
Coal	2.3	2.3	2.1
Na_2SO_4	0.6	0.7	0.8
Frit/Waste Ratio	70.2/29.8	71.3/27.7	70.2/29.8

* Composite is average feed glass. High-Al is high aluminum glass. High-Fe is high iron glass.

** Zeolite Composition: See Table 21.

TABLE 16

Calculated Heat Capacity*, of SRP Simulated Waste Glasses†**

Temp, °C	Reference cal/(gm)(°C)		High-Fe cal/(gm)(°C)		High-Al cal/(gm)(°C)	
	C_{pm}	C_{pt}	C_{pm}	C_{pt}	C_{pm}	C_{pt}
0	0.186	0.186	0.168	0.168	0.173	0.173
100	0.213	0.237	0.198	0.224	0.201	0.225
200	0.234	0.271	0.221	0.262	0.223	0.261
300	0.251	0.296	0.239	0.289	0.240	0.286
400	0.264	0.314	0.254	0.309	0.254	0.305
500	0.276	0.328	0.267	0.324	0.266	0.319
600	0.285	0.338	0.277	0.335	0.275	0.330
700	0.293	0.346	0.286	0.345	0.284	0.339
800	0.300	0.353	0.294	0.348	0.291	0.346
900	0.307	0.359	0.301	0.358	0.298	0.352
950	0.309	0.361	0.304	0.361	0.300	0.354
1000	0.312	0.363	0.307	0.363	0.303	0.356
1025	0.313	0.364	0.308	0.364	0.304	0.357
1050	0.315	0.365	0.309	0.365	0.306	0.358
1075	0.316	0.366	0.311	0.366	0.307	0.359
1100	0.317	0.367	0.312	0.367	0.308	0.360
1125	0.318	0.368	0.313	0.368	0.309	0.361
1150	0.319	0.369	0.314	0.369	0.310	0.362
1175	0.320	0.369	0.316	0.370	0.312	0.363
1200	0.321	0.370	0.317	0.371	0.313	0.364
1250	0.323	0.372	0.319	0.372	0.315	0.365
1300	0.325	0.373	0.321	0.373	0.317	0.366

* C_{pm} = mean heat capacity

** C_{pt} = true heat capacity

† For waste glass composition, see Table 15

TABLE 17

Measured Densities of SRP Simulated Waste Glass

Waste Glass Type	Composition	Density, g/cm^3*
Composite	See Table 15	2.75
High-Al	See Table 15	2.60
High-Fe	See Table 15	2.82

* At 25°C.

TABLE 18

Calculated Density of Simulated SRP Waste Glasses*

Temp, °C	Composite g/cm³	High-Fe g/cm³	High-Al g/cm³
0	2.750	2.820	2.600
100	2.743	2.813	2.593
200	2.735	2.804	2.585
300	2.726	2.795	2.577
400	2.718	2.786	2.569
TR*	2.713	2.781	2.565
500	2.672	2.721	2.520
600	2.575	2.607	2.432
700	2.481	2.499	2.348
800	2.391	2.396	2.266
900	2.305	2.298	2.188
1000	2.223	2.204	2.113
1025	2.202	2.181	2.094
1050	2.183	2.159	2.076
1075	2.163	2.137	2.058
1100	2.143	2.115	2.040
1125	2.124	2.093	2.023
1150	2.105	2.072	2.006
1175	2.086	2.051	1.988
1200	2.068	2.031	1.971

* Transition Temperature: T_r (Composite) = 459°C
T_r (High-Fe) = 448°C
T_r (High-Al) = 451°C

Note: See Table 15 for waste glass composition.

TABLE 19

Calculated Thermal Conductivity*, of SRP Simulated Waste Glasses†**

Temp, °C	Composite K_{rad}	Composite K_{eff}	High-Fe K_{rad}	High-Fe K_{eff}	High-Al K_{rad}	High-Al K_{eff}
0	0	0.489	0	0.467	0	0.539
100	0	0.562	0	0.548	0	0.566
200	0	0.634	0	0.629	0	0.592
300	0	0.706	0	0.710	0	0.619
400	0	0.779	0	0.791	0	0.645
500	0	0.851	0	0.872	0	0.672
600	0	0.923	0	0.952	0	0.699
670	3.5E-3	0.974	0	1.01	0	0.717
685	-	1.011	5.70E-3	1.03	0	0.721
700	4.83E-2	1.044	2.64E-2	1.06	1.62E-3	0.725
800	2.45E-1	1.313	2.03E-1	1.32	3.02E-1	1.05
900	5.20E-1	1.660	4.51E-1	1.65	7.47E-1	1.53
1000	8.73E-1	2.085	7.69E-1	2.05	1.32	2.12
1025	9.72E-1	2.200	8.60E-1	2.16	1.48	2.29
1050	1.08	2.33	9.54E-1	2.27	1.65	2.47
1075	1.18	2.45	1.05	2.39	1.83	2.65
1100	1.30	2.58	1.15	2.51	2.01	2.84
1125	1.41	2.71	1.27	2.64	2.19	3.03
1150	1.53	2.85	1.37	2.77	2.38	3.22
1175	1.65	2.99	1.48	2.90	2.58	3.43
1200	1.78	3.14	1.59	3.03	2.78	3.64

* K_{rad} = radiative conductivity in Btu-ft/hr-ft^2-°F

** K_{eff} = effective conductivity in Btu-ft/hr-ft^2-°F

† For waste glass composition, see Table 15

Note: To convert from $\frac{\text{Btu-ft}}{\text{hr-ft}^2\text{-°F}}$ to $\frac{\text{cal-cm}}{\text{sec-cm}^2\text{-°C}}$, divide by 242

TABLE 20

	Zeolite Composition Wt Percent
SiO_2	48.0
H_2O	19.1
Al_2O_3	18.6
Na_2O	4.1
CaO	10.2
	100.0

TABLE 21

Canister Decay Heat & Activity

Year	Sludge-Only Glass Curies/Can	Sludge-Only Glass Watts/Can	Sludge-Supernate Glass Curies/Can	Sludge-Supernate Glass Watts/Can
5	139,200	399	176,700	470
10	100,400	344	137,900	397
15	83,700	301	118,100	360
20	72,720	268	103,700	320
25	62,990	239	91,680	285
30	56,510	214	81,290	255
35	49,990	191	72,140	228
40	44,260	171	64,050	204
45	39,210	154	56,890	183
50	34,740	138	50,540	164
60	27,310	112	39,910	132
70	21,510	91	31,540	107
80	16,960	75	25,250	87
90	13,400	62	19,760	71
100	10,610	52	15,670	58
200	1255	12	1728	12
300	295	5.5	314	4.7
400	136	3.2	119	2.6
500	84	2.1	71	1.7
600	61	1.6	51	1.3
700	49	1.3	41	1.1
800	42	1.1	35	0.93
900	38	1.0	31	0.83
1000	35	0.92	29	0.76

TABLE 22

Radiation from Reference Canister of Sludge-Only Glass

Basis	Case I	Case II
Fill height, in.	91	91
Glass density, g/cm^3	2.37	2.56
Waste loading, %	28	28
Canister design	W753156-A	W753156-A

Distance, ft	Radiation Level, rems/hr	Radiation Level, rems/hr
Contact	1065	1020
1/3	825	775
1	360	330
3	125	115
4	85	80
5	63	58
10	20	19
15	10	9
20	5.7	5.2
30	2.6	2.4
60	0.66	0.61
100	0.24	0.22

TABLE 23

Source Terms for Sludge-Only Glass

Energy, keV	Cases I & II $0.625m^3$ Glass Photons/sec
100	1.165E14
125	6.988E13
225	4.618E12
375	1.462E13
575	1.328E14
850	2.210E13
1250	3 492E13
1750	7.145E11
2250	3.185E12
2750	1.095E10
3500	1.533E09

- Source Model: Cylinder volume source with self-absorption.
- Computations were made using the Shielding Design Calculation Code (SDC), ORNL - 3041, UC-32.

TABLE 24

Radiation from Canister of Sludge-Supernate Glass

Basis	Case III	Case IV	Case V
Fill height, in.	91	91	107
Glass density, g/cm^3	2.37	2.56	2.56
Waste loading, %	28	28	35
Canister design	W753156-A	W753156-A	W753156-A

Distance, ft	Radiation Level, rems/hr	Radiation Level, rems/hr	Radiation Level, rems/hr
Contact	5500	5275	6550
1/3	4150	3895	4825
1	1785	1660	2135
3	610	565	735
4	425	395	520
5	315	290	390
10	102	95	135
15	49	45	65
20	28	26	38
30	13	12	17
60	3.3	3	4.4
100	1.2	1.1	1.6

TABLE 25

Source Terms for Sludge-Supernate Glass

Energy, keV	Cases III & IV 0.625 m^3 Glass Photons/sec	Case V 0.734 m^3 Glass Photons/sec
100	1.723E14	2.533E14
125	5.678E13	8.346E13
225	3.756E12	5.520E12
375	1.189E13	1.747E13
575	1.350E15	1.985E13
850	2.442E13	3.589E13
1250	2.881E13	4.235E13
1750	5.808E11	8.537E11
2250	2.588E12	3.804E12
2750	8.900E09	1.308E10
3500	1.246E09	1.832E09

- Model: Cylinder volume source with self absorption
- Computations were made using the Shielding Design Calculation Code (SDC), ORNL - 3041, UC-32.

TABLE 26

Reference Canister Temperatures*

Watts	Surface Temp, °C	Centerline Temp, °C	Surrounding Air Temp, °C
425	34	50	20
510	54	71	38
1000	66	120	38

* Reference DWPF Sludge-Supernate waste form; canister 24-in. outside diameter by 118 in. high; 22 ft^3 of waste glass containing 28% sludge oxides, and air convection cooling.

FIGURES

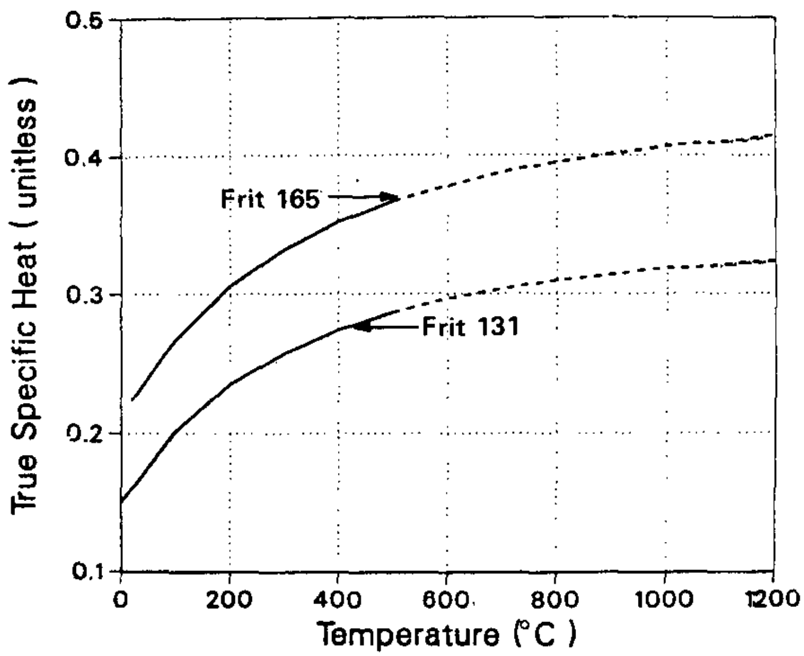

FIGURE 1. True Specific Heat as a Function of Temperature

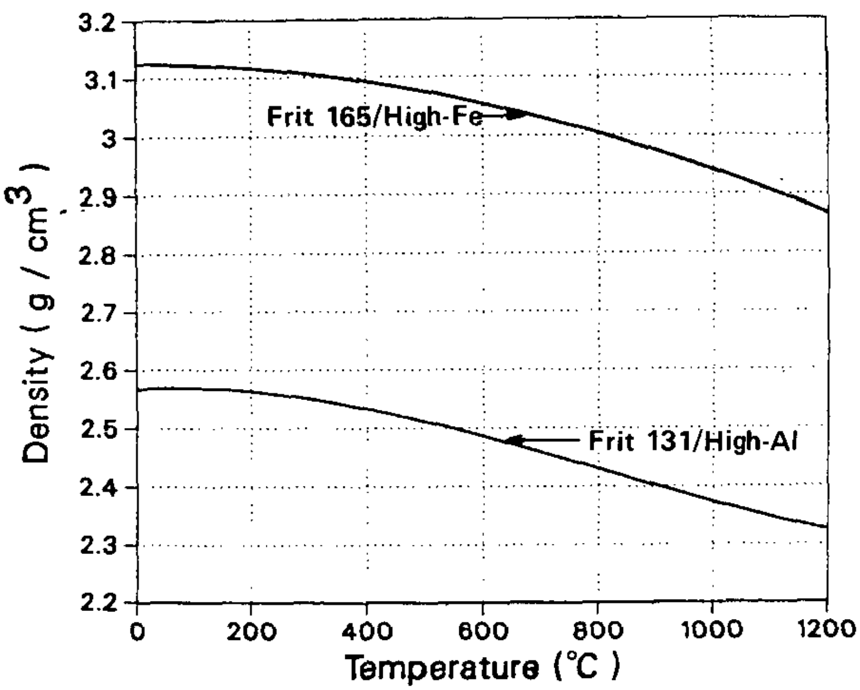

FIGURE 2. Glass Density as a Function of Temperature

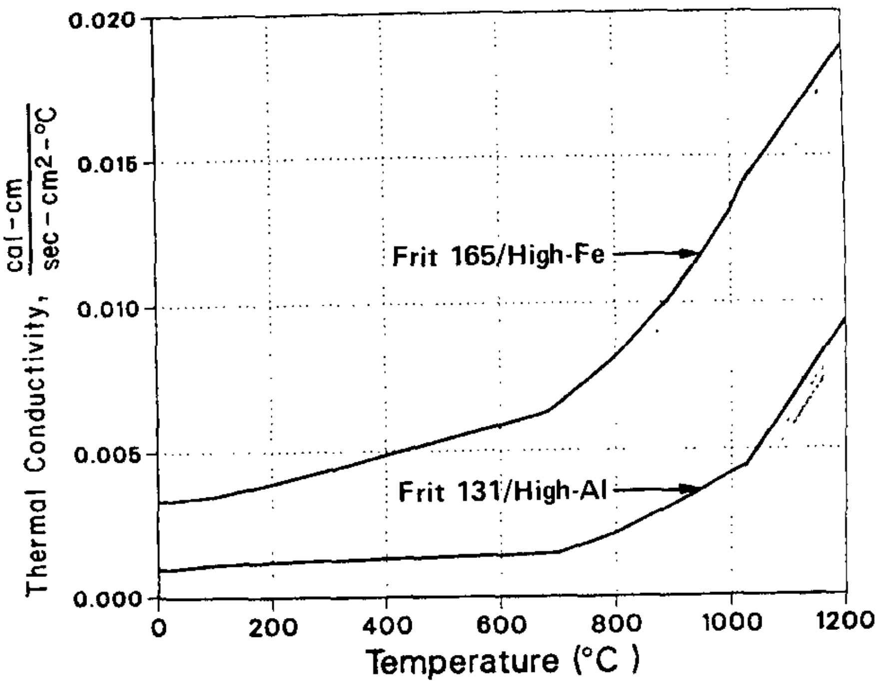

FIGURE 3. Thermal Conductivity as a Function of Temperature

Note: To convert from $\frac{cal-cm}{sec-cm^2-°C}$ to $\frac{Btu-ft}{hr-ft^2-°F}$, multiply by 242

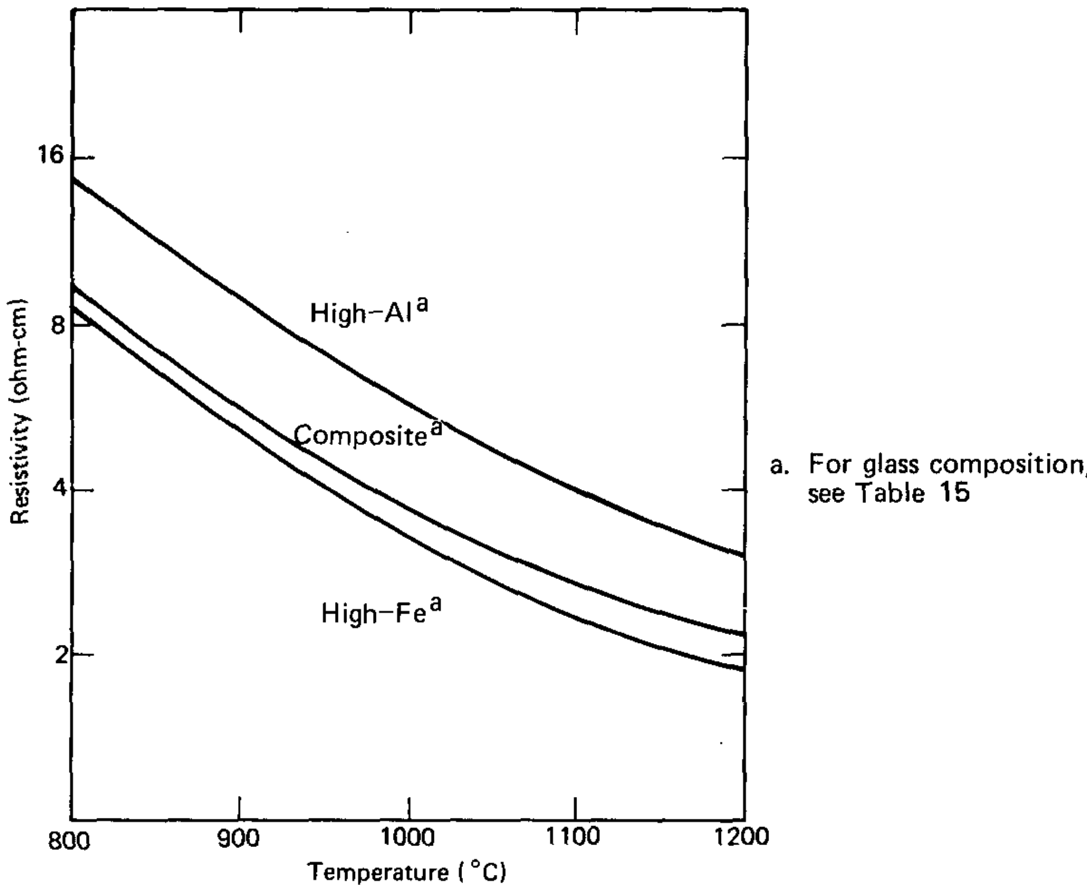

FIGURE 4. Experimental Resistivity Data for Simulated Waste Glass

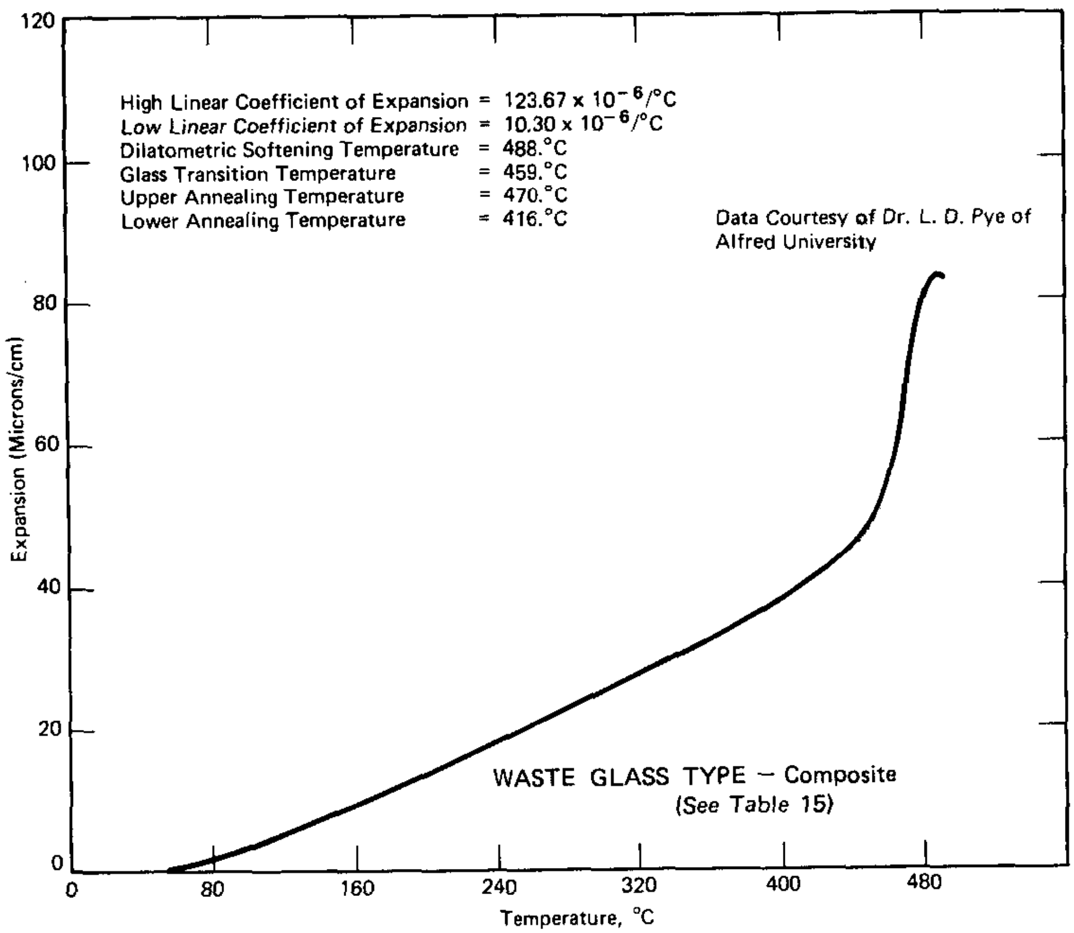

FIGURE 5. Experimental Thermal Expansion Data for Simulated Composite Waste Glass

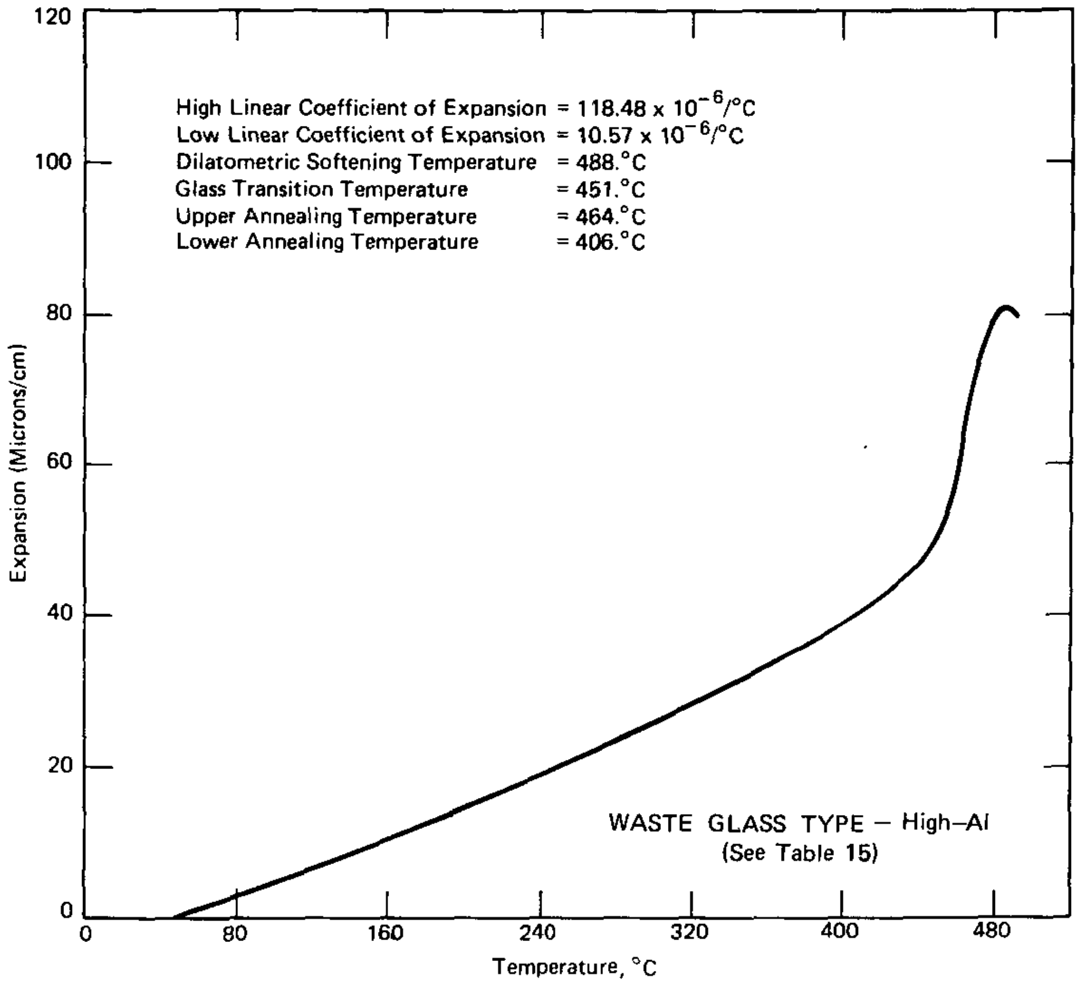

FIGURE 6. Experimental Thermal Expansion Data for Simulated High-Al Waste Glass

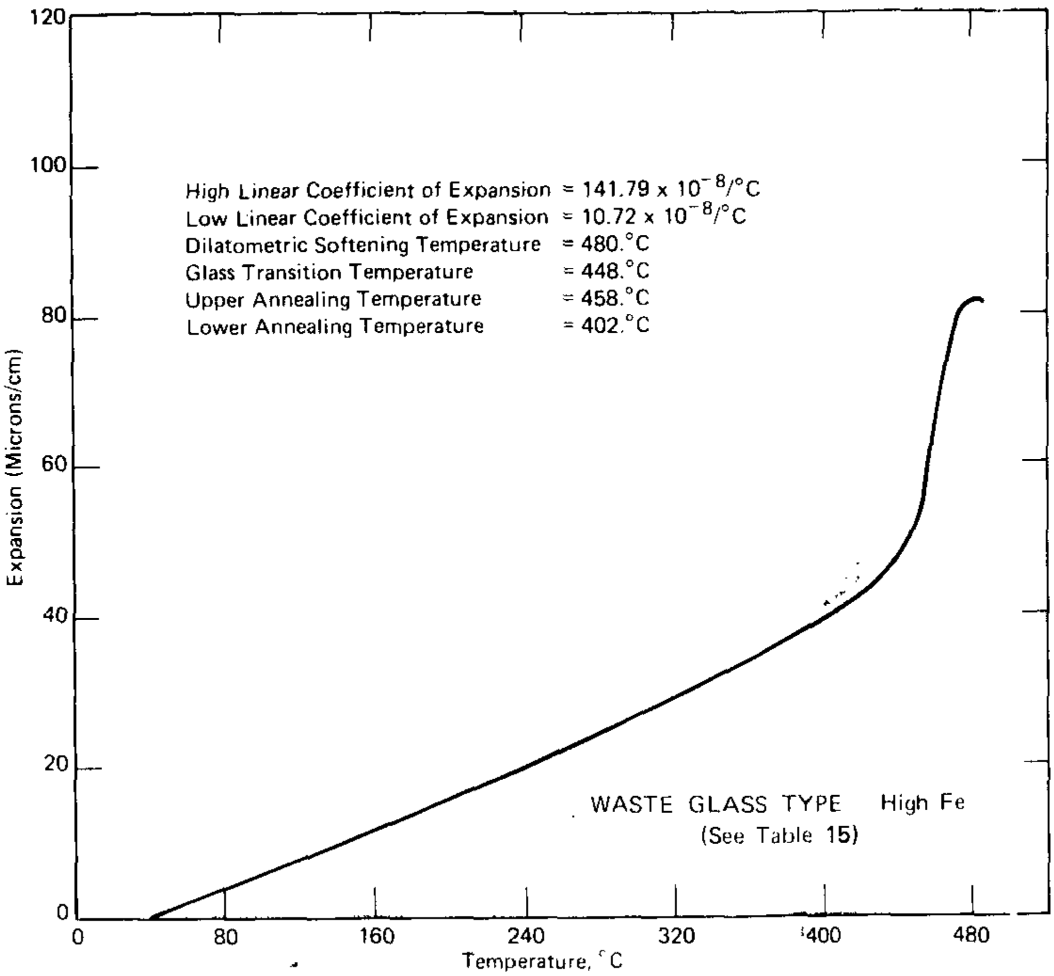

FIGURE 7. Experimental Thermal Expansion Data for Simulated High-Fe Waste Glass

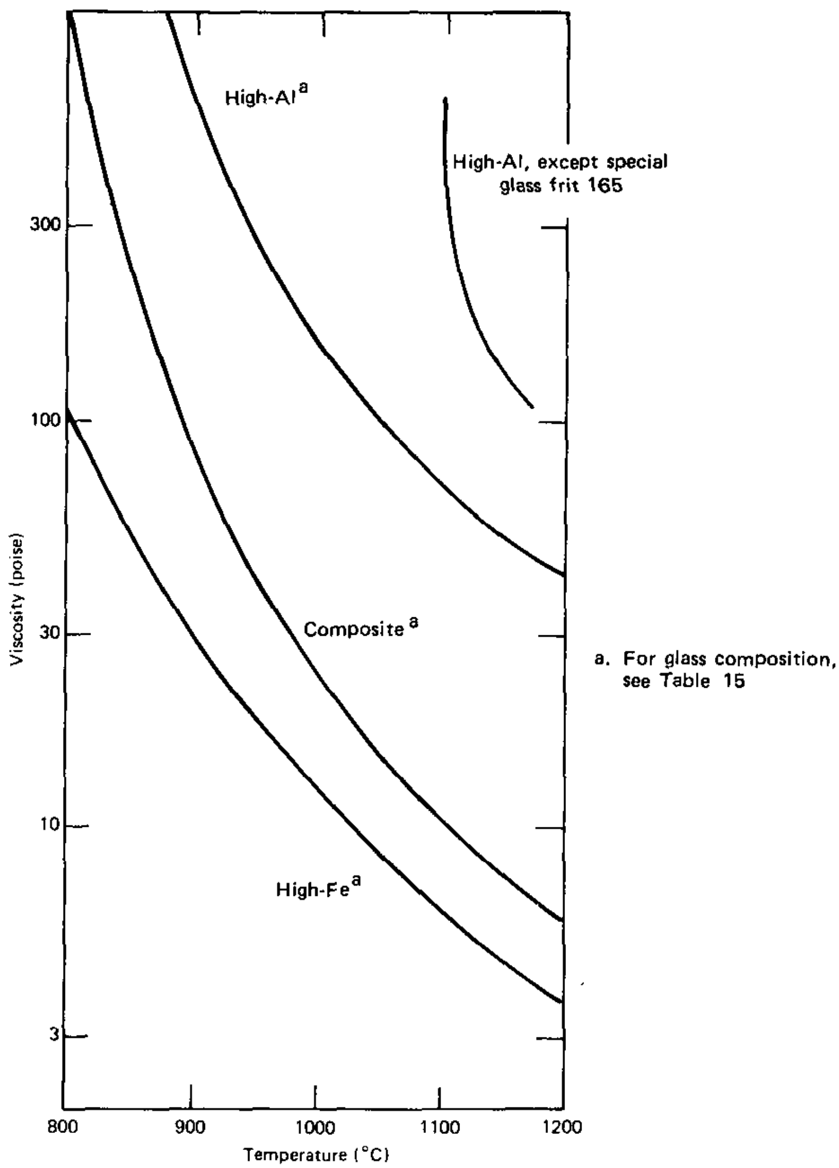

FIGURE 8. Experimental Viscosity Data for Simulated Waste Glass

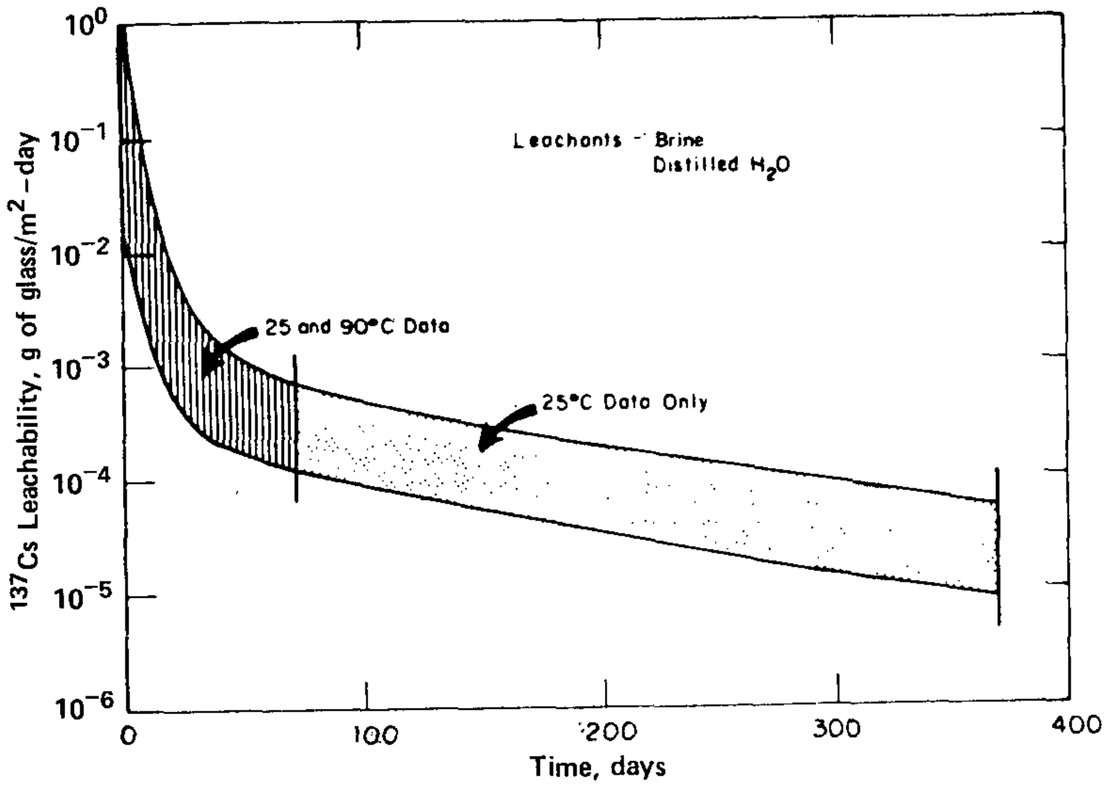

FIGURE 9. Published Leach Rates of SRP Glasses

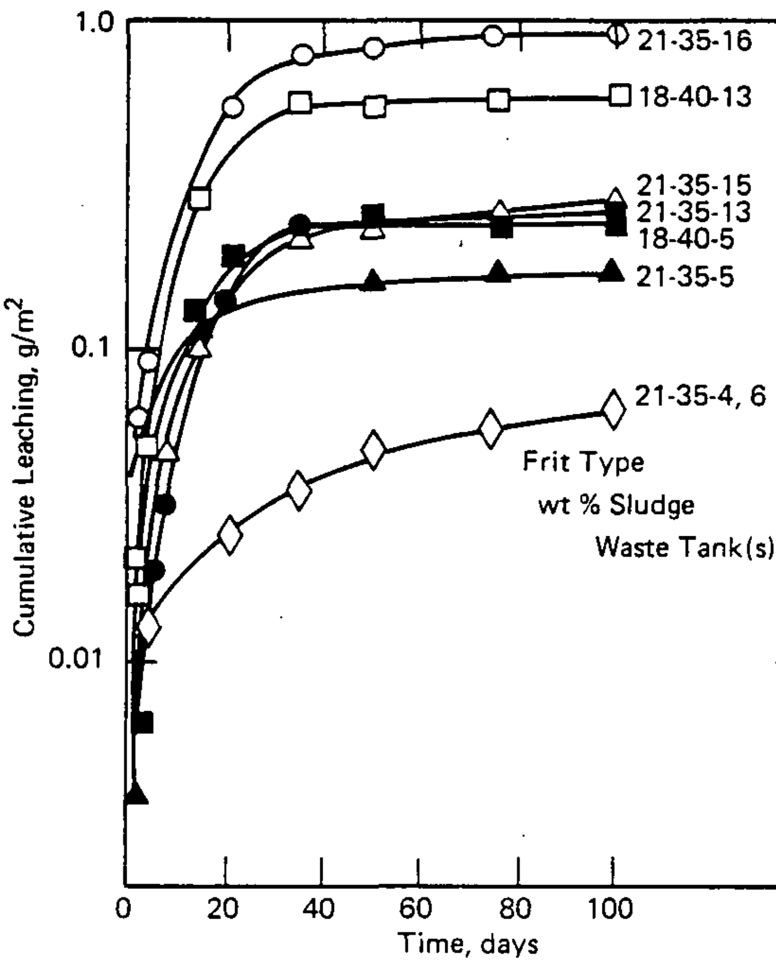

FIGURE 10. Cumulative Leaching of Actual SRP Waste Glass Based on Cs-137

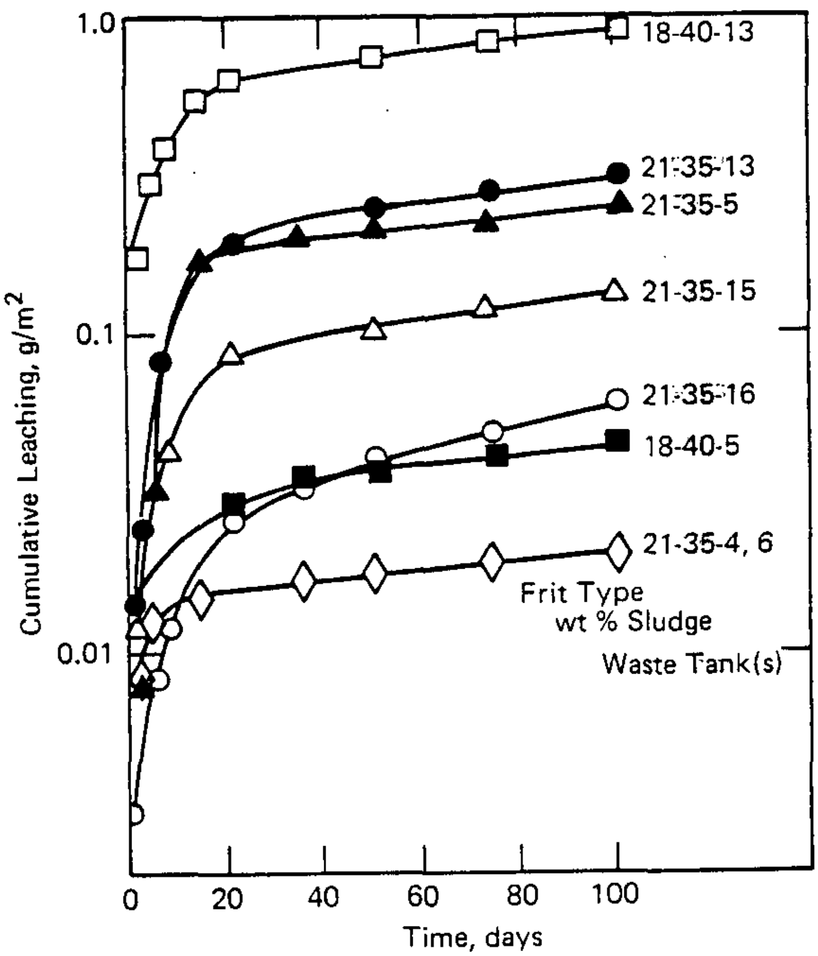

FIGURE 11. Cumulative Leaching of Actual SRP Waste Glass Based on Sr-90

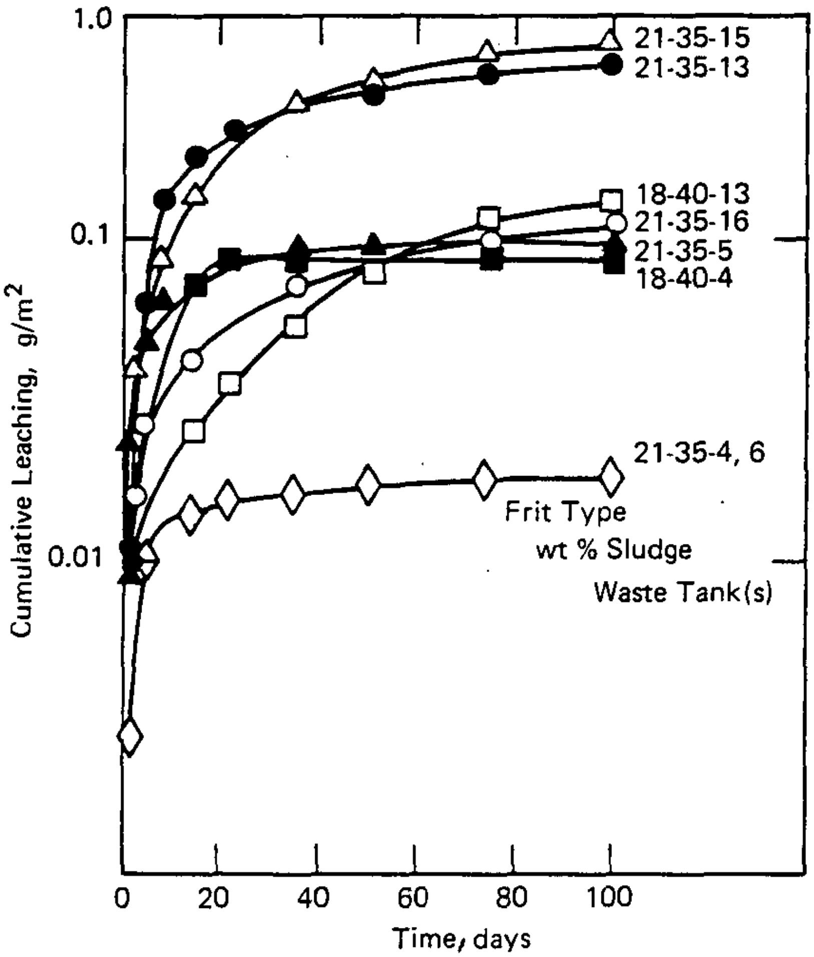

FIGURE 12. Cumulative Leaching of Actual SRP Waste Glass Based on Pu Analysis

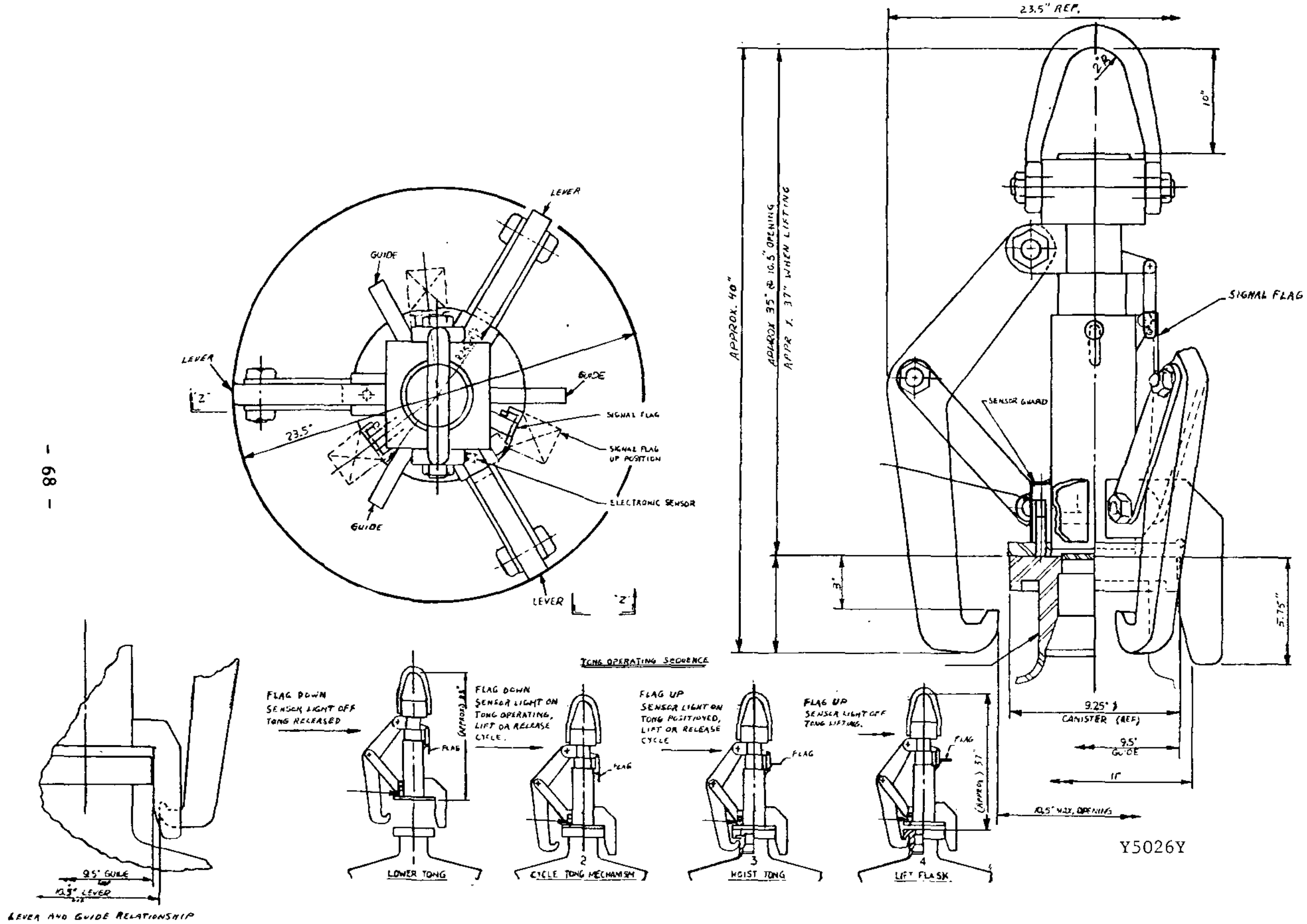

FIGURE 13. Lifting Grapple Tong Arrangement

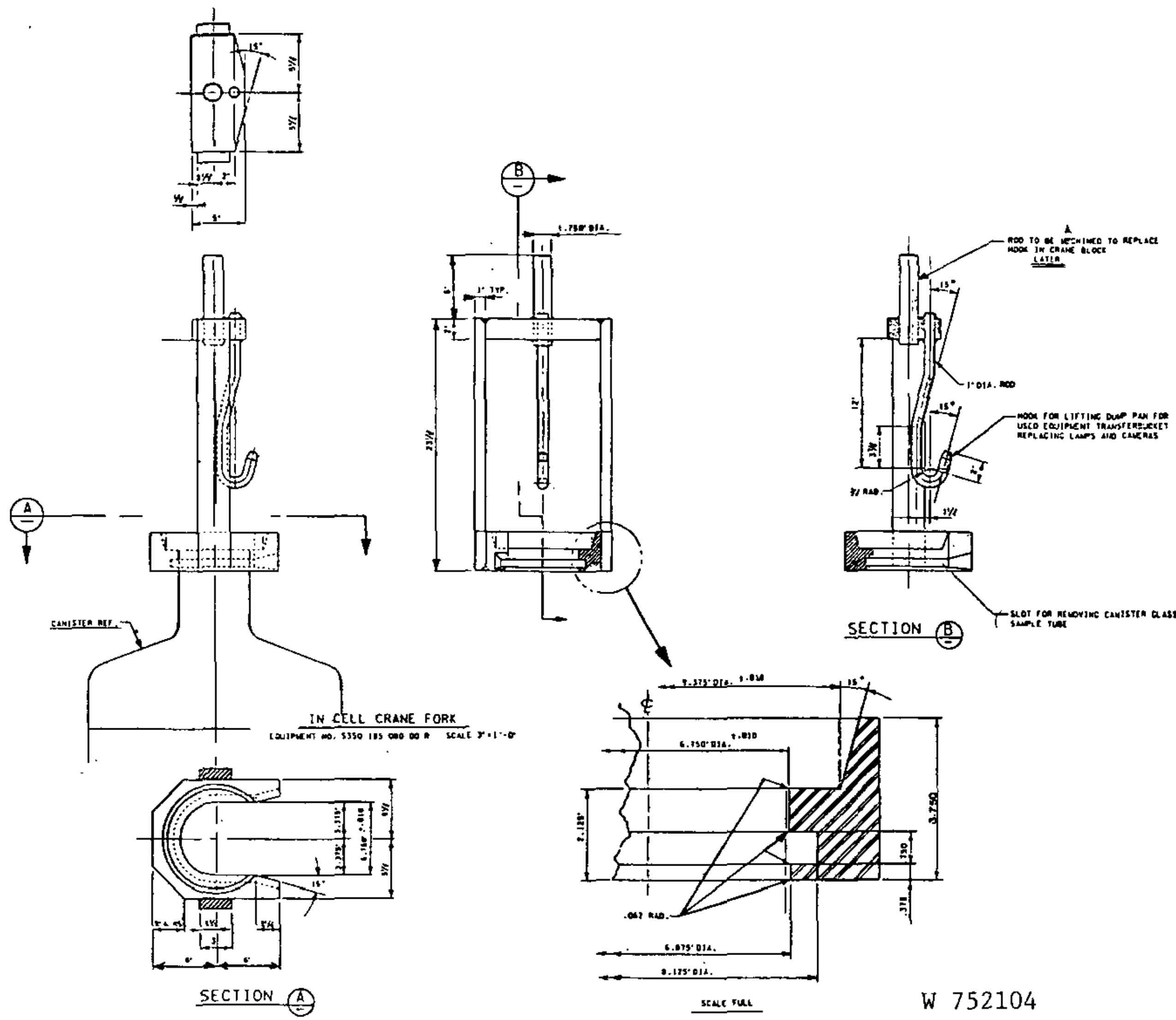

FIGURE 14. Crane Fork and Hook

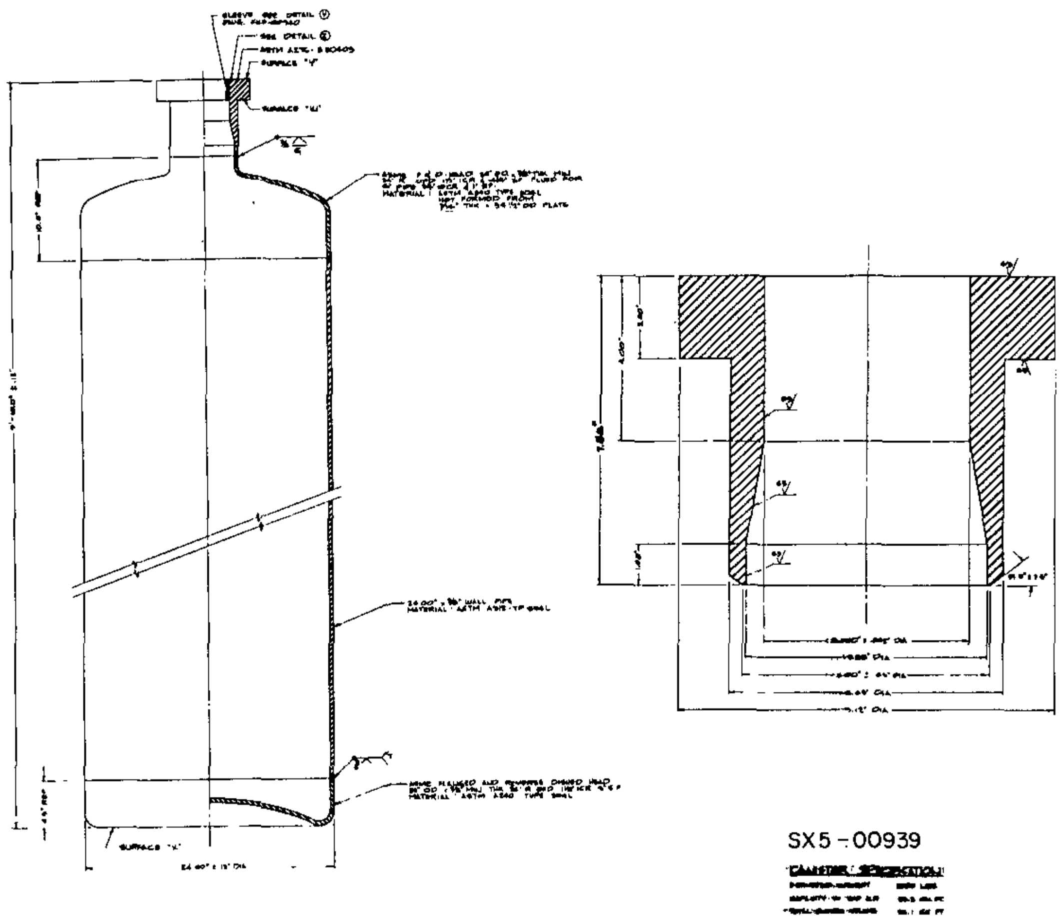

FIGURE 15. Canister Assembly

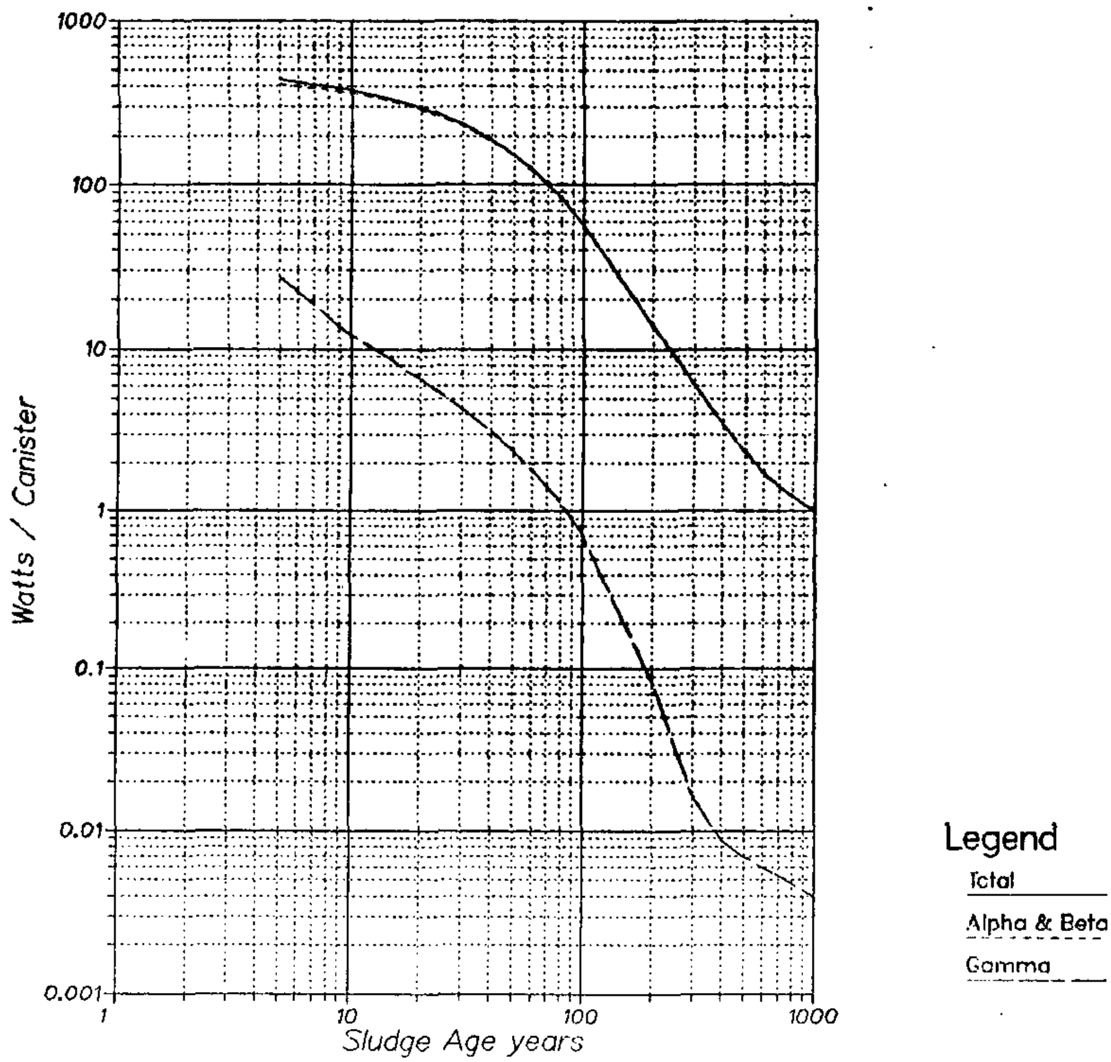

FIGURE 16. Canister Decay Heat, Sludge-Only Glass

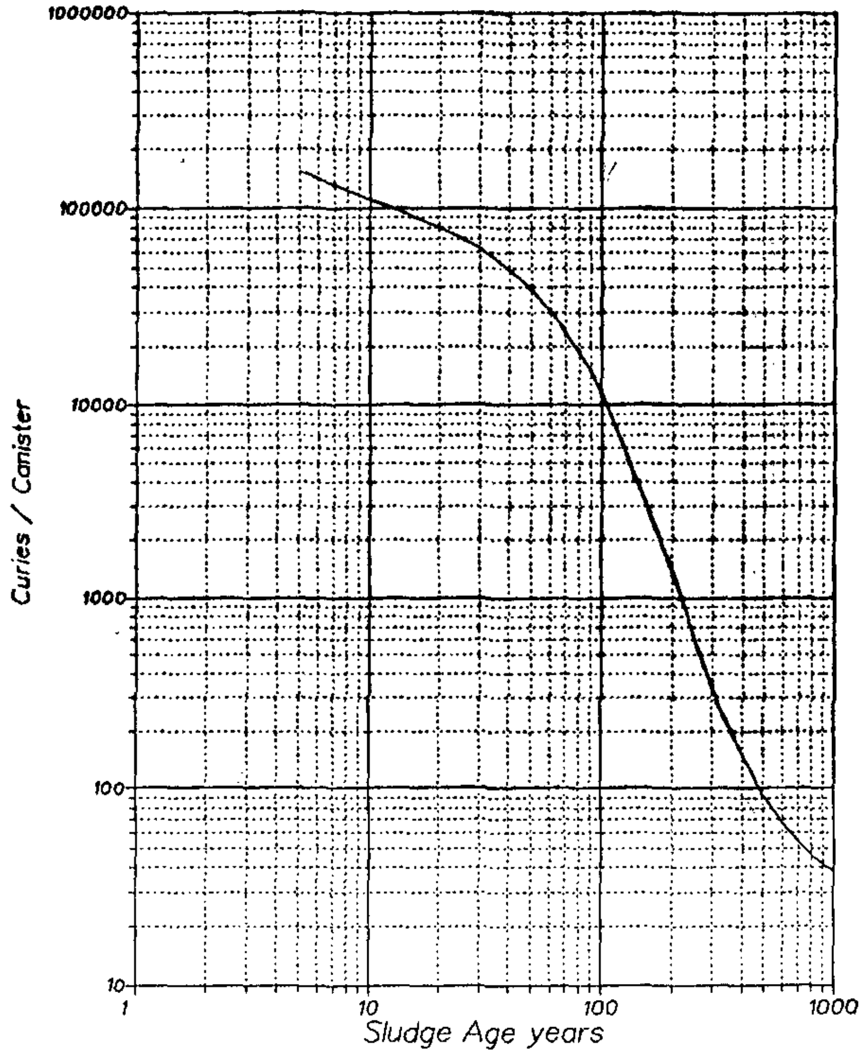

FIGURE 17. Canister Activity, Sludge-Only Glass

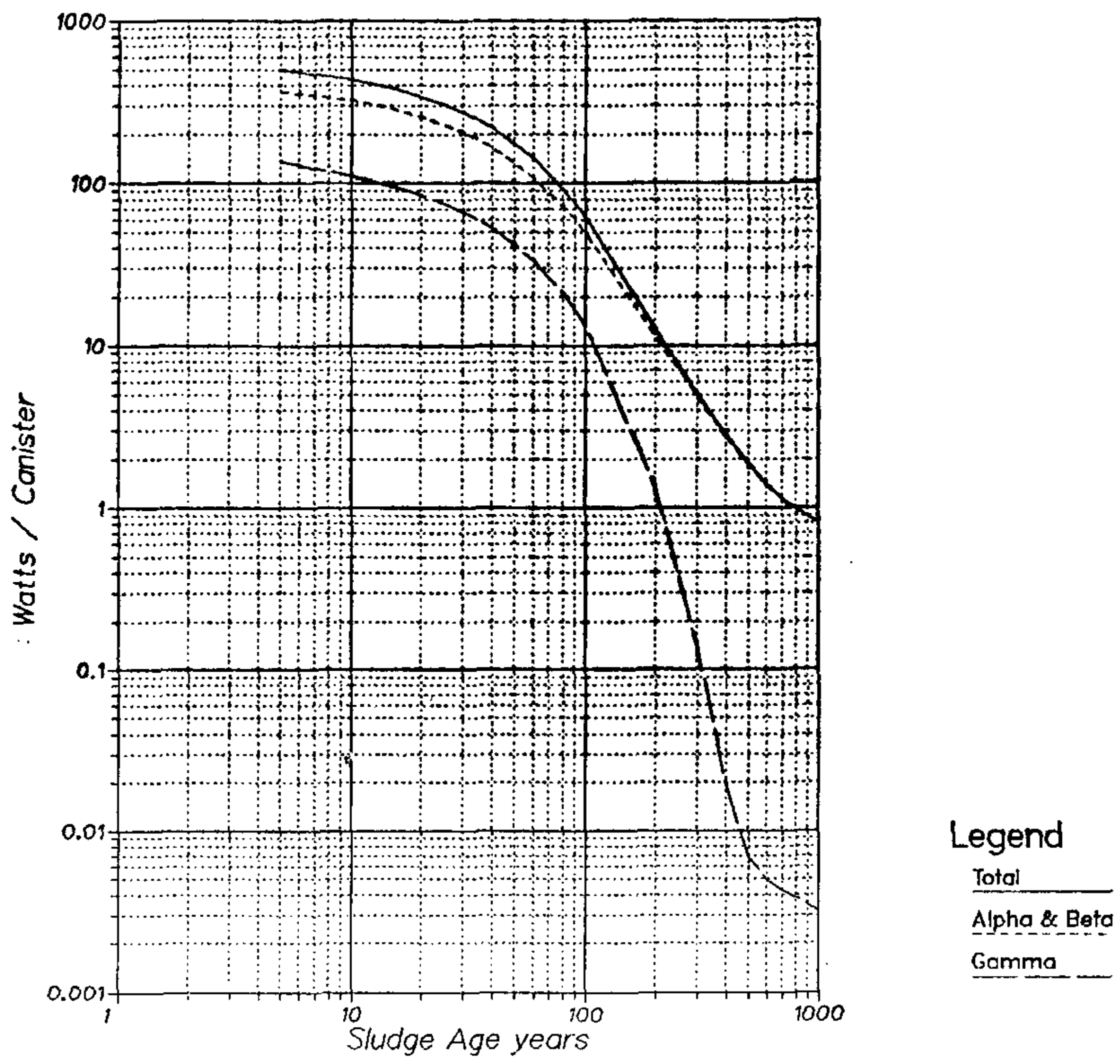

FIGURE 18. Canister Decay Heat, Sludge-Supernate Glass

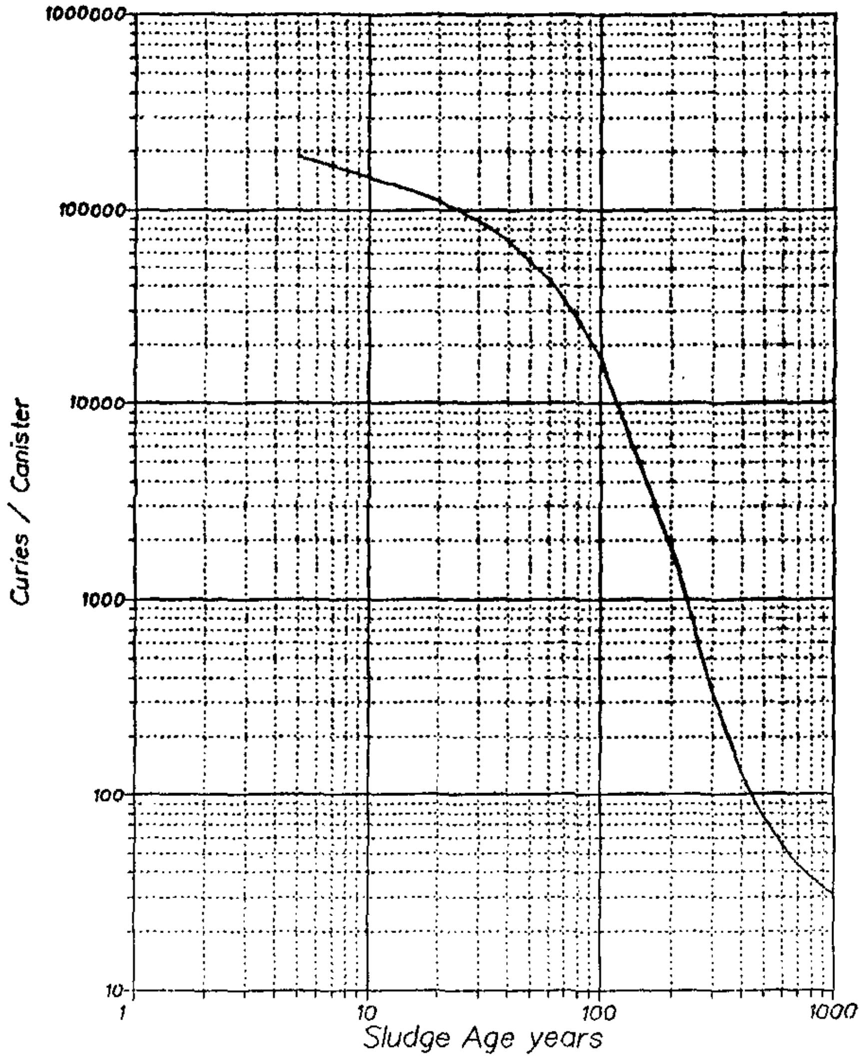

FIGURE 19. Canister Activity, Sludge-Supernate Glass