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DESCRIPTION OF THE WEST VALLEY DEMONSTRATION PROJECT REFERENCE HIGH-LEVEL WASTE FORM AND CANISTER

By
Larry R. Eisenstatt

July 28, 1986

Work Performed Under Contract No. AC07-81NE44139

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Progress Report for Period of
January - July 1986

By
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Work Performed Under Contract No. DE-AC07-81NE 44139

Prepared for
U.S. Department of Energy
Assistant Secretary for Nuclear Energy

Prepared by
West Valley Nuclear Services Co., Inc.
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TOPICAL REPORT

DESCRIPTION OF THE WEST VALLEY DEMONSTRATION PROJECT
REFERENCE HIGH-LEVEL WASTE FORM AND CANISTER

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ACKNOWLEDGMENTS

The glass chemical durability data were generated at the Vitreous State Laboratory at the Catholic University of America. The glass physical properties data were generated at the Institute of Glass Science and Engineering at Alfred University. The efforts of their personnel is greatly appreciated.

ABSTRACT

This document provides information on the West Valley Demonstration Project (WVDP) reference HLW form and canister. The WVDP will solidify the liquid HLW remaining at the commercial nuclear fuel reprocessing plant at West Valley, New York.

The reference waste form is borosilicate glass with a zeolite loading of 10 weight percent and a waste sludge loading of 23 weight percent. The glass formers that will be added to the waste during vitrification include Si, Al, B, and Na. Twenty-eight day and longer term leach tests show that the glass has adequate leach resistance. The room temperature density of the glass is 2.7 g/cm^3. Glass viscosity is 100 poise at 1049°C. Upper and lower linear expansion coefficients are 99.02 x 10^{-6}/°C and 10.76 x 10^{-6}°/C, respectively. The glass transition temperature is about 470°C.

The reference canister will be fabricated from stainless steel 304. The length will be 300 cm, and the diameter will be 61 cm. The canister wall will be sheet with a minimum thickness of 0.34 cm. The bottom will be a flanged and reverse dished head with a thickness of 0.48 cm; the top will be an ASME flanged and dished head. The lifting flange will be fabricated from square bar. Each canister will be uniquely labeled on the shoulder and side of the canister.

The maximum gamma dose rate of an average canistered waste form at time of production is expected to be 8,500 R/hr. Canistered waste standing in 25°C air will have a centerline temperature of less than 45°C. The weight of a 100 percent full glass filled canister will be 2,480 kg.

DESCRIPTION OF THE WEST VALLEY DEMONSTRATION PROJECT

REFERENCE HIGH-LEVEL WASTE FORM AND CANISTER

By: L. R. Eisenstatt

July 28, 1986

PREFACE

This is a report of information that was previously issued as report number WVD-056 with the same title. Only minor editorial changes are the difference between this report and WVDP-056.

1.0 INTRODUCTION

The WVDP will solidify the liquid HLW remaining at the former commercial nuclear fuel reprocessing plant at West Valley, New York. This document provides information on the reference WVDP HLW product. The emphasis for the type of information presented is that which will assist organizations that must plan to interface with the waste and that which will be required to be presented by the Waste Acceptance Preliminary Specifications[1] (WAPS). This report is not a Waste Qualification Report as required by the WAPS. It is comparable to the previously prepared "Description of Defense Waste Processing Facility Reference Waste Form and Canister"[2] that describes the reference Savannah River Plant vitrified HLW and canister.

The HLW that will be treated by the WVDP resulted from the PUREX and THOREX reprocessing methods. The current reference HLW composition is shown in Tables 1 - 3. The PUREX waste is stored in HLW Storage Tank 8D-2, and the THOREX waste is stored in Tank 8D-4. Tanks 8D-1 and 8D-3 are spare storage tanks for the PUREX and THOREX wastes, respectively. The waste that will be immobilized in the glass will be PUREX solids, THOREX, and cesium loaded zeolite IE-96 (see Table 4). The PUREX solids are predominately hydroxide precipitates from the neutralization of a nitric acid solution. The THOREX waste is predominately nitrates in a nitric acid solution. The cesium in the PUREX supernatant will be removed by zeolite IE-96 ion exchange material. The decontaminated supernatant will be solidified in the Cement Solidification System (CSS) and disposed as low-level waste. The cesium loaded zeolite will be mixed with the PUREX solids, THOREX, and glass formers (see Table 5) and melted in the West Valley Melter. The nominal waste loading of the glass will be about 23 weight percent waste oxides and about 10 weight percent zeolite. The reference radioactivity that is included in the waste is shown in Table 6. It is expected that the activities for the fission products U, and Pu may vary about five percent from these values. Th may vary about 20 percent. The remaining actinides may vary about 50 percent.

A flow diagram of the West Valley reference HLW vitrification process is shown in Figure 1. It is planned for the zeolite and THOREX waste to be transferred and mixed with the PUREX solids in HLW Storage Tank 8D-2 where the PUREX waste is currently stored. The slurried waste will be transferred to the Concentrator Feed Makeup Tank (CFMUT), sampled, and concentrated. Alternatively, the waste streams will be fed individually to the CFMUT. Bulk glass formers will be added to the CFMUT; the amount will depend upon process instrumentation readings and the sample analysis results. After mixing, the waste will be transferred to the Melter Feed Tank (MFT), sampled, and then metered to the Slurry Fed Ceramic Melter (SFCM) via an Air Displacement (ADS) pump. After melting, molten glass will overflow into a stainless steel canister. Following cool down, the canisters will be moved to and stored in the Chemical Process Cell of the existing reprocessing plant facility.

2.0 HIGH-LEVEL WASTE FORM COMPOSITION AND CHARACTERISTICS

2.1 COMPOSITION

The HLW form for the WVDP is borosilicate glass and the reference composition is WV-205. The composition of WV-205 is given in Table 7; note that Table 7 includes a nominal composition and a potential range for the major components. These ranges are based on uncertainties in the analysis of waste samples and expected variations in the waste stream fed to the vitrification facility. The nominal composition is given to four decimal places to show the presence of minor constituents in the waste. Testing of these ranges for processibility and characterizing them for durability may cause this range of expected glass compositions to be modified. During processing, this would be done by altering the cold chemical (glass former) composition.

2.2 RADIOACTIVITY

The activity that is expected to be immobilized in the waste on a per canister basis is given in Table 8; a nominal and a range is provided. These values are based on an activity balance that considers the volatilization and carry over of certain components into the Melter off-gas. The canister geometry is as discussed in Section 3.1. The nominal values assumes the canister is 85 percent full, and the waste activity is at its nominal values. The lower bound is for an 80 percent full canister, and the waste activity is at its low values. The upper bound is for a 90 percent full canister, and the waste activity is at its high value.

2.3 CHEMICAL DURABILITY

The durability of WV-205 is being investigated. Table 9 presents the composition of a nonradioactive analogue of WV-205 that has undergone durability testing. Zr is used as a substitute for the actinides in the waste. Tables 10 to 15 present data for MCC-1[3] and pulsed flow testing.[4,5] Some of this data already has been presented elsewhere[6]. The test glasses were melted in the full scale SFCM at West Valley or a laboratory

scale Melter. The MCC-1 tests used deionized water at 90°C for 28 days. Monoliths with geometric surface areas of 400 mm^2 were used, and the specimens surface area to leachate volume ratio was 10 m^{-1}. The glass had a surface finish of either a 200 grit as-cut finish or a 600 grit polished finish; as the results show the surface finish had little affect on the leach rates. The pulsed flow tests used deionized water at 90°C; 25 percent of it was exchanged every seven days for 12 weeks when the results were observed to approach constant values. Tables 10 to 15 shows that glass from either source had no significant difference in leach rates. Generally, these values are comparable to those for Defense Waste Reference Glass (DWRG),[6,7] a simulated waste glass composition based on optimization studies of glass compositions for defense wastes at the Savannah River Plant.[8] This is illustrated in Figure 2 for the pulsed flow test. Durability testing is continuing. West Valley glass doped with Th and U, variations of WV-205, and ATM-10 (glass doped with Tc, Th, U, Np, Pu, and Am) will be tested. The use of repository ground waters will be incorporated into the test matrix.

2.4 GLASS PHYSICAL PROPERTIES

Other WVDP glass waste form physical properties are summarized in Table 16 and discussed below. The room temperature density of glass melted in the full-scale melter and cooled in a canister is 2.695 g/cm^3. After annealing at 460°C for two hours, the glass density is 2.699 g/cm^3. These densities were measured using the sink float method.[9] An unknown glass and a standard glass are placed in a liquid of known density. The temperature of the liquid is varied. The difference between the temperatures when the known glass and unknown glass floats are related to the difference in their densities.

The temperature at which the glass viscosity is 100 poise is 1049°C±5°C. Table 16 includes the Fulcher relationship for WV-205 which describes the viscosity behavior of the glass as a function of temperature. Table 17 lists annealing range viscosity data measured with a beam bending viscometer; Table 18 presents high temperature viscosity data measured with a rotating spindle viscometer. Figure 3 plots this data with the calculated Fulcher curve.

The upper and lower linear expansion coefficients (α) of WV-205 have been measured at 99.02 x 10^{-6}/°C (±5 percent) and 10.76 x 10^{-6}/°C (±5 percent), respectively. A linear expansion versus temperature curve for WV-205 is shown in Figure 4. This data was obtained from a dilatometer. The upper and lower volume expansion coefficients (β) are 297.06 x 10^{-6}°C and 32.28 x 10^{-6}/°C, respectively. The volumetric expansion coefficients were calculated from the measured linear expansion coefficients using the equation for isotropic materials:

$$\beta = (1 + \alpha)^3 - 1.$$

The glass transition temperature of nominal WV-205 was measured by dilatometry and Differential Scanning Calorimetry (DSC) and is included in Table 16. The glass transition temperature was measured by DSC on WV-205 for various waste and zeolite loadings and is reported in Table 19. The glass transition temperature ranged from 451.3°C to 494.8°C. Measurements for other glass compositions will also be performed. The dilatometric softening point of WV-205 is 506±5°C.

Heat capacity data are listed in Table 20, and a plot of the heat capacity versus temperature is shown in Figure 5. The upper and lower annealing points are 453±5°C and 484±5°C, respectively.

3.0 WVDP HLW CANISTER

3.1 CANISTER DIMENSIONS

The reference WVDP canister is shown in Figure 6 (Drawing Number D-7868). The principal dimensions and tolerances before glass pouring are:

length (without lid*)	299.09 cm + 0.16 cm, - 0.32 cm
outer diameter	60.96 cm ± 0.16 cm
minimum wall thickness**	0.34 cm
parallelism and perpendicularity	0.13 cm
surface finish	125 rms
internal volume	827 litres
weight, empty	234 kg

The dimensions and tolerances after filling and closure will be:

length	300.0 cm + 0.5 cm, - 2.0 cm
outer diameter	61.0 cm + 1.5 cm, - 1.0 cm
overall	can fit in a 64.0 cm diameter by 301 cm long right circular cylinder
weight 80% full	2,020 kg
85% full (nominal)	2,130 kg
90% full	2,240 kg
100% full	2,480 kg

---

* Once the permanent closure lid is placed on the canister, the overall length will be 300 cm.

** Parts of the canister wall will be thicker than the minimum; see Figure 6.

The canister dimensions are based on the requirements of the WAPS.[1] The tolerances before glass pouring are based on fabrication tolerances, and the after pouring tolerances are from the WAPS. The WVDP is planning to fill its canisters nominally 85 percent full with an expected range of 80 percent to 90 percent.

3.2 MATERIAL OF CONSTRUCTION

The WVDP canister will be fabricated from austenitic stainless steel ASTM A240, and A479 UNS Designation S30400. The composition of this alloy is shown in Table 21.

3.3 CANISTER FABRICATION

Canister fabrication will be in accordance with the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B/PV) Code Section VIII Division 1. No code stamp will be required on the canister.

The WVDP plans to have its canister fabricated by cold rolling stainless steel sheet with a minimum thickness of 0.34 cm to form the canister wall. The canister bottom will be a flanged and reverse dished head; the top will be an ASME flanged and dished head. The top and bottom thicknesses are shown to be 0.48 cm in Figure 6. The lifting flange will be formed by cold rolling square bar. Fabrication welding will be by gas tungsten arc welding.

The welders, operators, and procedures will be qualified according to ASME B/PV Section IX. Grinding and wire brushing operations will be free of carbon steel contamination. After fabrication, the canister will have no leak rate greater than 10^{-4} atm-cm^3/sec He per ASME B/PV Code Section V, Article 10, Appendix 4 after the opening is temporarily sealed. During fabrication, handling, cleaning, testing, and shipping measures will be taken to assure that the canister surfaces are not contaminated with compounds that may induce stress corrosion.

3.4 LABELING

Each West Valley canister will have an identification code of the form **WVXXX** where X is a digit. This identification code will be on two places on the canister. One will be on the shoulder of the canister such that the code can be seen from the vertical direction; the other will be on the side of the canister 152 cm from the bottom as shown in Figure 7. The characters for these labels will be at least 3 cm tall and will be modified block. It is planned that these characters will be stamped on a tag which will be welded onto the canister.

3.5 CANISTER HANDLING

The canister lifting flange geometry is included in Figure 6. A conceptual design of the grapple being tested at West Valley is shown in Figure 8. The design of the grapple is being remotized. The grapple is being designed and will be tested to verify that it will be capable of meeting the requirements below without penetrating the walls of an imaginary right circular cylinder with diameter equal to the canister.

- The grapple will be capable of being remotely engaged and disengaged from the flange.

- The grapple, when attached to a hoist and when engaged with the flange, will be capable of raising and lowering a canistered waste form in a uniaxial vertical direction.

- The grapple, in the disengaged position, will be capable of being inserted into and withdrawn from a right circular cylindrical cavity with diameter equal to that of the canistered waste form in a uniaxial vertical direction.

Furthermore, the grapple is being designed to up right a canister from the horizontal position.

4.0 CANISTERED WASTE FORM CHARACTERISTICS

4.1 MAXIMUM DOSE RATE

The expected maximum gamma dose rate from the canistered waste at time of production is estimated to be 8,500 R/hr per canister. An expected range is 7,500 to 9,500 R/hr.

The gamma source strength was used in ANISN, a one dimensional discrete ordinates transport code, which solves multigroup Boltzman transport equations for gamma fluxes in cylindrical geometry. It uses cross section data containing 18 gamma groups. The energy dependent flux at the surface of the West Valley canister was calculated assuming the source was uniformly distributed inside the canister. The resulting energy dependent flux surface was converted into gamma dose using appropriate conversion factors. Anisotropic scattering was treated by general legendre polynomial expansion of scattering cross section making the calculation valid for deep penetration of gamma flux.

4.2 HEAT GENERATION RATE

The expected nominal heat generation rate for the West Valley canistered waste at time of production is 340 watts per canister. An expected range is 300 to 390 watts per canister.

4.3 CANISTERED GLASS TEMPERATURE

The maximum centerline temperature of a filled WVDP canister is expected to be less than 45°C when the surrounding air temperature is 25°C. This is for a canister filled with 2,000 kg of HLW glass producing 390 watts of decay heat uniformly distributed in the glass; it is assumed that the temperature drop across the air film is 5°C. Table 22 gives the temperature distribution in a canister at the midplane as a function of distance from the axis and at the axis as a function of distance from the bottom. This was calculated by using the heat source as an input in the thermal analysis program HEATING 5 obtained from the National Energy Software Center at Argonne National Laboratories.

4.4 GAS GENERATION

It has been estimated that up to 2,830 cm^3 of gas at standard temperature and pressure may be generated in 100 years in a WVDP canister due to radioactive decay. This is a result of the decay of Th-232, U-234, U-235, and U-238. The gas generation includes 50 cm^3 of radon and 2,780 cm^3 of helium. If the gas diffuses through the glass to the canister void space which generally will be no less than 10 percent then this gas generation would increase the pressure by about three percent over a one hundred year period.

4.5 FISSIONABLE MATERIAL CONTENT

The fissionable material content of canistered waste is shown in Table 23. The activity of the fissionable isotopes of Table 8 were converted to their masses by dividing by their respective specific activities listed in Table A-1 of 10 CFR 71. A criticality assessment showed that the reactivity (K-infinity) of a canister with vitrified HLW will be less than 0.1.

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TABLE 1A: PUREX INSOLUBLE SOLIDS CHEMICAL COMPOSITION

	Component	Mass (kg)
	$Fe(OH)_3$	66,040
	$FePO_4$	6,351
	$Al(OH)_3$	5,852
	AlF_3	536
	MnO_2	4,581
	$CaCO_3$	3,208
	$UO_2(OH)_2$	3,087
	$Ni(OH)_2$	1,088
	SiO_2	1,263
	$Zr(OH)_4$ (a)	159
	$MgCO_3$	826
	$Cu(OH)_2$	376
	$Zn(OH)_2$	128
	$Cr(OH)_3$	65
	$Hg(OH)_2$	23
Fission Products (b)		
	F.P. hydroxides	1,485
	R.E. hydroxides	1,484
	F.P. sulfates	520
Transuranics		
	NpO_2	35
	PuO_2	37
	AmO_2	28
	CmO_2	0.4
Total		97,172

a) Excludes fission product zirconium

b) See Table 1B for breakdown

TABLE 1B: PURRENT

Components	kg in Solids
$SrSO_4$	217
$Y(OH)_3$	103
$Zr(OH)_4$	805
$Ru(OH)_4$	458
$Rh(OH)_4$	79
$Pd(OH)_2$	34
AgOH	0.7
$Cd(OH)_2$	1.7
$In(OH)_3$	0.3
$Sn(OH)_4$	2.5
$Sb(OH)_3$	0.7
$BaSO_4$	303
Rare Earths	
$La(OH)_3$	185
$Ce(OH)_3$	354
$Pr(OH)_3$	170
$Nd(OH)_3$	621
$Pm(OH)_3$	1.5
$Sm(OH)_3$	143
$Eu(OH)_3$	7.5
$Gd(OH)_3$	1.7

TABLE 2: PUREX SUPERNATANT CHEMICAL COMPOSITION

Compound	Wt. % Wet Basis	Wt. % Dry Basis	Mass (Kg)
$NaNO_3$	21.10	53.38	602,659
$NaNO_2$	10.90	27.57	311,326
Na_2SO_4	2.67	6.76	76,261
$NaHCO_3$	1.49	3.77	42,557
KNO_3	1.27	3.21	36,274
Na_2CO_3	0.884	2.24	25,249
NaOH	0.614	1.55	17,537
K_2CrO_4	0.179	0.45	5,113
NaCl	0.164	0.42	4,684
Na_3PO_4	0.133	0.34	3,799
Na_2MoO_4	0.0242	0.06	691
Na_3BO_3	0.0209	0.05	597
$CsNO_3$	0.0187	0.05	534
NaF	0.0176	0.04	503
$Sn(NO_3)_4$	0.00859	0.02	245
$Na_2U_2O_7$	0.00808	0.02	231
$Si(NO_3)_4$	0.00806	0.02	230
$NaTcO_4$	0.00620	0.02	177
$RbNO_3$	0.00416	0.01	119
Na_2TeO_4	0.00287	0.007	82
AlF_3	0.00271	0.007	77
$Fe(NO_3)_3$	0.00152	0.004	43
Na_2SeO_4	0.00054	0.001	15
$LiNO_3$	0.00048	0.001	14
H_2CO_3	0.00032	0.0008	9
$Cu(NO_3)_3$	0.00022	0.0005	6
$Sr(NO_3)_2$	0.00013	0.0004	4
$Mg(NO_3)_2$	0.00008	0.0002	2
TOTAL	39.53	100.00	1,129,038
H_2O (by difference)	60.47		1,727,164

TABLE 3: THOREX WASTE CHEMICAL COMPOSITION

A. Solution

Compound	Wt. %	Mass (Kg)
$Th(NO_3)_4$	26.69	12,997
$Fe(NO_3)_3$	19.41	9,452
$Al(NO_3)_3$	9.57	4,660
HNO_3	4.88	2,376
$Cr(NO_3)_3$	4.40	2,143
$Ni(NO_3)_2$	1.81	881
H_3BO_3	1.10	536
$NaNO_3$	0.759	370
Na_2SO_4	0.414	202
KNO_3	0.294	143
Na_2SiO_3	0.290	141
K_2MnO_4	0.281	137
$Nd(NO_3)_3$	0.146	71
$Mg(NO_3)_3$	0.131	64
$NaCl$	0.115	56
Na_2MoO_4	0.114	56
$Ca(NO_3)_2$	0.0700	34
$Ba(NO_3)_2$	0.0697	34
$Ru(NO_3)_4$	0.0643	31
$CsNO_3$	0.0502	24
Na_2TeO_4	0.0410	20
$Sr(NO_3)_2$	0.0407	20
$Ce(NO_3)_3$	0.0387	19
$Zr(NO_3)_4$	0.0288	14
$Sm(NO_3)_3$	0.0286	14

TABLE 3: THORUX WASTE CHEMICAL COMPOSITION (CONTINUED)

Compound	Wt. %	Mass (Kg)
$La(NO_3)_3$	0.0269	13
$Pr(NO_3)_3$	0.0267	13
$Zn(NO_3)_2$	0.0226	11
$Rh(NO_3)_4$	0.0222	11
Na_2TcO_4	0.0206	10
$UO_2(NO_3)_2$	0.0156	8
$Y(NO_3)_3$	0.0134	7
Na_2SeO_4	0.00767	4
$RbNO_3$	0.00619	3
$Co(NO_3)_2$	0.00505	2
$Pd(NO_3)_4$	0.00469	2
NaF	0.00244	1
$Cu(NO_3)_2$	0.00177	0.9
$Pu(NO_3)_4$	0.00152	0.7
$Em(NO_3)_3$	0.00142	0.7
$Gd(NO_3)_3$	0.00037	0.2
$X^*(NO_3)_4$	0.00035	0.2
$Pm(NO_3)_2$	0.00034	0.2
Total	71.02	34,583
H_2O (by diff.)	28.98	14,114

B. Solids

$Th(NO_3)_4$	-	18,958
Insolubles	-	39

*Am-241, Am-243, Cm-242, Cm-243, Cm-244, Cm-245

TABLE 4: IE-96 NOMINAL COMPOSITION

Component	IE-96 COMPOSITION	LOADED IE-96 TO MELTER**	
	Wt. %	Mass (kg)	Wt. %
Na_2O	7.9	3,603	7.8
K_2O	1.0	460	1.0
MgO	0.8	368	0.8
CaO	1.2	552	1.2
BaO	0.1	46	0.1
SiO_2	67.4	31,004	66.9
Al_2O_3	17.3	7,958	17.2
Fe_2O_3	4.0	1,840	4.0
TiO_2	0.2	92	0.2
Cs_2O	----	3,781	0.8
TOTAL	100.0	46,301	100.0

* Per Union Carbide, anhydrous basis

** 30 CV basis, 100 percent recovery from storage

TABLE 5: GLASS FORMERS ADDED TO WEST VALLEY HLW TO MELT WV-205

Component
Al_2O_3
KNO_3
LiOH
$Mg(NO_3)_2 \cdot 6H_2O$
$Na_2B_4O_7 \cdot 10H_2O$
NaCOOH
SiO_2
TiO_2

TABLE 6: REFERENCE 1987 RADIONUCLIDE CONTENT (CURIES) OF WEST VALLEY WASTE

	PUREX			
Radionuclide	Supernatant	Solids	THOREX	Total
3-H	9.5E+1	~0	<2.0E+0	9.5E+1
14-C	1.4E+2	~0	...	1.4E+2
55-Fe	~0	1.0E+3	...	1.0E+3
59-Ni	~0	8.2E+1	...	8.2E+1
63-Ni	8.9E+2	6.4E+3	...	6.4E+3
60-Co	~0	4.7E+0	1.2E+3	1.2E+3
79-Se	3.7E+1	~0	...	3.7E+1
90-Sr	2.9E+3	6.9E+6	5.0E+5	7.4E+6
90-Y	2.9E+3	6.9E+6	5.0E+5	7.4E+6
93-Zr	~0	2.3E+2	...	2.3E+2
93m-Nb	~0	2.3E+2	...	2.3E+2
99-Tc	1.6E+3	~0	8.0E+1	1.7E+3
106-Ru	~0	1.3E+2	<3.1E-1	1.3E+2
106-Rh	~0	1.3E+2	<3.1E-1	1.3E+2
107-Pd	~0	1.2E+0	...	1.2E+0
125-Sb	4.8E+1	4.5E+3	...	4.5E+3
125m-Te	1.1E+1	1.0E+3	...	1.0E+3
126-Sn	~0	4.0E+1	...	4.0E+1
126m-Sb	~0	4.0E+1	...	4.0E+1
126-Sb	~0	5.6E+1	...	5.6E+1
129-I	2.1E-1	~0	<1.5E-1	<3.6E-1
134-Cs	1.4E+4	~0	2.9E+2	1.4E+4
135-Cs	1.6E+2	~0	...	1.6E+2
137-Cs	7.3E+6	~0	5.1E+5	7.8E+6
137m-Ba	6.8E+6	~0	4.8E+5	7.3E+6
144-Ce	2.9E-5	1.4E+1	<2.0E-2	1.4E+1
144-Pr	2.9E-5	1.4E+1	<2.0E-2	1.4E+1
147-Pm	1.7E+2	3.1E+5	4.5E+3	3.1E+5

TABLE 6: REFERENCE 1987 RADIONUCLIDE CONTENT (CURIES) OF WEST VALLEY WASTE (CONTINUED)

Radionuclide	PUREX Supernatant	PUREX Solids	THOREX	Total
151-Sm	1.1E+0	2.1E+5	1.5E+1	2.1E+5
152-Eu	4.2E-2	4.2E+2	5.8E+0	4.2E+2
154-Eu	1.4E+1	1.3E+5	2.6E+3	1.3E+5
155-Eu	2.3E+0	2.3E+4	3.1E+2	2.3E+4
232-Th	~0	~0	1.6E+0	1.6E+0
233-U	4.9E-1	6.9E+0	2.6E+0	1.0E+1
234-U	2.9E-1	4.0E+0	3.0E-1	4.6E+0
235-U	6.4E-3	8.9E-2	4.9E-3	1.0E-1
236-U	1.9E-2	2.7E-1	1.0E-2	3.0E-1
238-U	5.7E-2	7.9E-1	6.1E-4	8.5E-1
237-Np	~0	1.1E+1	...	1.1E+1
239-Np	~0	2.4E+3	...	2.4E+3
238-Pu	1.3E+2	6.5E+3	5.3E+2	7.2E+3
239-Pu	2.5E+1	1.7E+3	1.7E+1	1.7E+3
240-Pu	1.9E+1	1.3E+3	9.0E+0	1.3E+3
241-Pu	1.5E+3	8.5E+4	9.3E+2	8.7E+4
242-Pu	2.5E-2	1.7E+0	1.3E-2	1.7E+0
241-Am	~0	7.2E+4	2.7E+2	7.2E+4
242-Am	~0	2.1E+1	...	2.1E+1
242m-Am	~0	2.1E+1	...	2.1E+1
243-Am	~0	2.4E+3	8.8E+0	2.4E+3
242-Cm	~0	2.2E+0	<1.1E-3	2.2E+0
243-Cm	~0	1.7E+2	5.0E-2	1.7E+2
244-Cm	~0	2.2E+4	1.6E+1	2.2E+4
245-Cm	~0	1.0E+1	1.2E-3	1.0E+1
246-Cm	~0	4.3E+0	...	4.3E+0

TABLE 7: COMPOSITION OF WV-205

Component	Nominal (Wt. %)	Range (Wt. %)	
AgO	0.0001	-	-
Al_2O_3	2.8295	1.19	7.15
AmO_2	0.0073	-	-
BaO	0.0540	0.04	0.08
B_2O_3	9.9516	9.33	10.66
CaO	0.5993	0.39	0.93
CdO	0.0003	-	-
CeO_2	0.0670	0.04	0.10
CmO_2	0.0001	-	-
CoO	0.0002	-	-
Cr_2O_3	0.3112	0.21	0.48
Cs_2O	0.0826	0.05	0.13
CuO	0.0001	-	-
Eu_2O_3	0.0014	-	-
Fe_2O_3	12.1573	8.32	18.50
Gd_2O_3	0.0003	-	-
In_2O_3	0.0001	-	-
K_2O	3.5733	3.36	3.84
La_2O_3	0.0337	0.02	0.05
Li_2O	3.0315	2.84	3.25
MgO	1.3032	1.22	1.39
MnO_2	1.3107	0.84	1.96
MoO_3	0.0088	-	0.01
NaCl	0.0183	0.01	0.03
NaF	0.0013	-	-
Na_2O	10.9335	10.25	11.71
Nd_2O_3	0.1209	0.08	0.19
NiO	0.3358	0.22	0.52

TABLE 7: COMPOSITION OF WV-205 (CONTINUED)

Component	Nominal (Wt. %)	Range (Wt. %)	
NpO_2	0.0224	0.01	0.03
P_2O_5	2.5084	0.21	3.16
PdO	0.0062	-	-
Pm_2O_3	0.0003	-	-
Pr_6O_{11}	0.0321	0.02	0.05
PuO_2	0.0076	-	-
Rb_2O	0.0005	-	-
RhO_2	0.0136	0.01	0.02
RuO_2	0.0759	0.05	0.12
SO_3	0.2164	0.14	0.33
Sb_2O_3	0.0001	-	-
SeO_2	0.0005	-	-
SiO_2	44.8770	42.08	48.10
Sm_2O_3	0.0267	0.02	0.04
SnO_2	0.0006	-	-
SrO	0.0269	0.02	0.04
Tc_2O_7	0.0021	-	-
ThO_2	3.5844	1.83	6.56
TeO_2	0.0028	-	-
TiO_2	0.9800	0.92	1.05
UO_2	0.5605	0.37	0.87
Y_2O_3	0.0177	0.01	0.03
ZnO	0.0010	-	-
ZrO_2	0.2943	0.19	0.45
Insolubles	0.0080	-	-

TABLE 8: REFERENCE RADIONUCLIDE CONTENT OF A CANISTER OF WVDP HLW (AT 1990)

Radionuclide	Radioactivity (Ci)		
	Nominal	Range	
55-Fe	1.9E+0	1.7E+0	2.1E+0
59-Ni	3.2E-1	2.9E-1	3.6E-1
63-Ni	2.5E+1	2.3E+1	2.7E+1
60-Co	3.2E+0	2.8E+0	3.6E+0
79-Se	1.5E-2	1.3E-2	1.6E-2
90-Sr	2.7E+4	2.4E+4	3.0E+4
90-Y	2.7E+4	2.4E+4	3.0E+4
93-Zr	9.5E-1	8.5E-1	1.1E+0
93m-Nb	7.8E-1	7.0E-1	8.6E-1
99-Tc	6.7E+0	6.0E+0	7.4E+0
106-Ru	3.2E-2	2.9E-2	3.6E-2
106-Rh	3.2E-2	2.9E-2	3.6E-2
107-Pd	4.7E-3	4.2E-3	5.3E-3
125-Sb	8.4E+0	7.5E+0	9.3E+0
125m-Te	1.9E+0	1.7E+0	2.1E+0
126-Sn	1.6E-1	1.4E-1	1.8E-1
126m-Sb	1.6E-1	1.4E-1	1.8E-1
126-Sb	2.2E-1	2.0E-1	2.5E-1
134-Cs	1.5E+1	1.3E+1	1.6E+1
135-Cs	6.3E-1	5.6E-1	7.0E-1
137-Cs	2.9E+4	2.5E+4	3.2+4
137m-Ba	2.7E+4	2.4E+4	3.0E+4
144-Ce	3.8E-3	3.4E-3	4.3E-3
144-Pr	3.8E-3	3.4E-3	4.3E-3
147-Pm	5.4E+2	5.0E+2	6.3E+2

TABLE 8: REFERENCE RADIONUCLIDE CONTENT OF A CANISTER OF WVDP HLW (AT 1990) (CONTINUED)

Radionuclide	Radioactivity (Ci) Nominal	Range	
151-Sm	8.1E+2	7.2E+2	9.0E+2
152-Eu	1.5E+0	1.3E+0	1.6E+0
154-Eu	4.0E+2	3.6E+2	4.5E+2
155-Eu	5.9E+1	5.3E+1	6.5E+1
232-Th	6.3E-3	4.7E-3	8.0E-3
233-U	3.8E-2	3.4E-2	4.2E-2
234-U	1.7E-2	1.6E-2	1.9E-2
235-U	3.9E-4	3.5E-4	4.4E-4
236-U	1.1E-3	9.9E-4	1.2E-3
238-U	3.1E-3	2.8E-3	3.5E-3
237-Np	4.3E-2	2.0E-2	6.9E-2
239-Np	9.4E+0	4.4E+0	1.5E+1
238-Pu	2.7E+1	2.4E+1	3.0E+1
239-Pu	6.8E+0	6.1E+0	7.6E+0
240-Pu	1.5E+1	8.7E+0	1.9E+1
241-Pu	3.0E+2	2.6E+2	3.3E+2
242-Pu	6.8E-3	6.0E-3	7.5E-3
241-Am	3.4E+2	1.7E+2	5.0E+2
242-Am	8.3E-2	3.8E-2	1.3E-1
242m-Am	8.3-2	3.8E-2	1.3E-1
243-Am	9.4E+0	4.4E+0	1.5E+1
242-Cm	8.3E-2	3.8E-2	1.3E-1
243-Cm	6.2E-1	3.0E-1	1.0E+0
244-Cm	7.8E+1	3.7E+1	1.2E+2
245-Cm	3.9E-2	1.9E-2	6.3E-2
246-Cm	1.7E-2	8.0E-3	2.7E-2

TABLE 9: COMPOSITION OF A NONRADIOACTIVE ANALOGUE WV-205

Component	Wt. %
Al_2O_3	3.31
B_2O_3	9.97
BaO	0.06
CaO	0.61
CeO_2	0.18
Cr_2O_3	0.22
Cs_2O	0.11
Fe_2O_3	11.83
K_2O	3.62
La_2O_3	0.12
Li_2O	3.00
MgO	1.24
MnO_2	1.73
Na_2O	11.05
NiO	0.70
P_2O_5	2.52
RuO_2	0.07
SO_3	0.14
SiO_2	45.25
SnO_2	0.13
SrO	0.13
TiO_2	0.99
Y_2O_3	0.03
ZrO_2	2.99

TABLE 10: WV-205/SFCM* MCC-1 TEST RESULTS**, 200 GRIT CUT FINISH SPECIMENS[6]

Component	Leachate Concentrations ($g \cdot m^{-3}$)	Normalized Leach Rates ($g \cdot m^{-2} \cdot d^{-1}$)
Si	30.1±0.9	0.46±0.01
B	6.7±0.2	0.69±0.02
P	1.7±0.1	0.50±0.04
Li	2.0±0.1	0.46±0.02
Na	15.1±0.9	0.59±0.04
K	6.0±0.2	0.67±0.02
Cs	0.07±0.01	0.23±0.03
Al	2.5±0.1	0.48±0.02
Ca	0.07±0.02	0.05±0.02
Mg	0.01±0.1	0.01±0.01
Fe	0.11±0.02	0.01±0.01
Mn	0.03±0.01	0.01±0.01
Ti	0.00±0.01	0.00±0.01
wt. loss		0.40±0.01
pH	9.37±0.01	

*Glass generated during a slurry feed run in the full scale WVDP Melter.

**Deionized water, 90°C, S/V = $10m^{-1}$, 28 days.

TABLE 11: WV-205/SFCM* MCC-1 TEST RESULTS**, 600 GRIT POLISH SPECIMENS

	Leachate Concentrations ($g \cdot m^{-3}$)	Normalized Leach Rates ($g \cdot m^{-2} \cdot d^{-1}$)
Si	24.8 ±0.3	0.42±0.01
B	5.4±0.1	0.63±0.01
P	1.45±0.07	0.47±0.02
Li	2.01±0.01	0.508±0.002
Na	11.0±0.7	0.48±0.03
K	3.96±0.07	0.49±0.01
Cs	0.06±0.01	0.23±0.02
Al	2.12±0.03	0.43±0.01
Sr	0.002±0.001	0.007±0.004
Ca	0.06±0.01	0.05±0.01
Mg	0.000±0.007	0.00±0.01
Fe	0.09±0.02	0.004±0.001
Cr	0.012±0.002	0.029±0.005
Mn	0.023±0.005	0.008±0.002
Ti	0.005±0.002	0.003±0.001
Zr	0.006±0.004	0.001±0.01
wt. loss		0.38±0.03

*Glass generated during a slurry feed run in the full scale WVDP Ceramic Melter.

**Deionized water, 90°C, S/V = $10m^{-1}$, 28 days.

TABLE 12: WV-205/SM* MCC-1 TEST RESULTS**, 200 GRIT CUT FINISH SPECIMENS[6]

Component	Leachate Concentrations ($g \cdot m^{-3}$)	Normalized Leach Rates ($g \cdot m^{-2} \cdot d^{-1}$)
Si	30.0±0.1	0.46±0.01
B	5.9±0.2	0.62±0.06
P	1.6±0.1	0.47±0.03
Li	2.5±0.3	0.60±0.10
Na	15.3±1.7	0.60±0.10
K	6.6±0.1	0.74±0.01
Cs	0.19±0.01	0.62±0.03
Al	2.5±0.1	0.47±0.02
Ca	0.04±0.1	0.03±0.01
Mg	0.01±0.01	0.01±0.01
Fe	0.12±0.01	0.01±0.01
Mn	0.02±0.01	0.01±0.01
Ti	0.02±0.01	0.00±0.01
wt. loss		0.40±0.01
pH	9.37±0.03	

*Glass generated in a laboratory scale melter.

**Deionized water, 90°C, S/V = $10m^{-1}$, 28 days.

TABLE 13: WV-205/SM* MCC-1 TEST RESULTS**, 600 GRIT POLISH SPECIMENS

Component	Leachate Concentrations ($g \cdot m^{-3}$)	Normalized Leach Rates ($g \cdot m^{-2} \cdot d^{-1}$)
Si	25.30±0.04	0.430±0.001
B	4.74±0.10	0.55±0.01
P	1.36±0.04	0.44±0.01
Li	2.11±0.02	0.53±0.01
Na	9.91±0.02	0.435±0.001
K	4.54±0.05	0.56±0.01
Cs	0.17±0.02	0.65±0.08
Al	2.09±0.04	0.43±0.01
Sr	0.003±0.001	0.011±0.004
Ca	0.045±0.002	0.037±0.002
Mg	-0.003±0.001	-0.001±0.001
Fe	0.10±0.01	0.005±0.001
Cr	0.013±0.002	0.031±0.005
Mn	0.016±0.003	0.005±0.001
Ti	0.005±0.003	0.003±0.002
Zr	-0.006±0.008	-0.001±0.001
wt. loss		0.37±0.02

*Glass generated in a laboratory scale melter.

**Deionized water, 90°C, S/V = $10m^{-1}$, 28 days.

TABLE 14: WV-205/SFCM* PULSED FLOW TEST RESULTS[6]

Component	Leachate Concentrations ($g \cdot m^{-3}$)	Normalized Leach Rates ($g \cdot m^{-2} \cdot d^{-1}$)
Si	52±2	0.030±0.001
B	14.9±0.6	0.059±0.002
P	4.8±0.2	0.054±0.002
Li	5.4±0.3	0.046±0.003
Na	36±2	0.054±0.003
K	8.8±0.3	0.037±0.001
Cs	0.08±0.01	0.009±0.001
Al	2.9±0.1	0.020±0.001
Ca	0.00±0.01	0.000±0.001
Fe	0.14±0.03	0.000±0.001
Mn	0.01±0.01	0.000±0.001
Ti	0.00±0.01	0.000±0.001
pH	9.62±0.01	

* Glass generated during a slurry feed run in the full scale WVDP Ceramic Melter.

** Deionized water, 90°C, S/V = 291m^{-1}, 25% exchange every 7 days.

TABLE 15: WV-205/SM* PULSED FLOW TEST RESULTS**[6]

Component	Leachate Concentrations ($g \cdot m^{-3}$)	Normalized Leach Rates ($g \cdot m^{-2} \cdot d^{-1}$)
Si	45±1	0.026±0.001
B	11.6±0.2	0.046±0.001
P	4.0±0.1	0.045±0.001
Li	4.7±0.3	0.040±0.002
Na	26±1	0.039±0.001
K	8.3±0.1	0.035±0.001
Cs	0.06±0.04	0.008±0.005
Al	3.1±0.1	0.022±0.001
Ca	0.00±0.02	0.000±0.001
Fe	0.16±0.02	0.000±0.001
Mn	0.02±0.01	0.000±0.001
Ti	0.01±0.01	0.000±0.001
pH	9.55±0.02	

* Glass generated during in a laboratory scale melter.

** Deionized water, 90°C, S/V = 291m^{-1}, 25% exchange every 7 days.

TABLE 16: WV-205 GLASS PHYSICAL PROPERTY DATA: SUMMARY

Room temperature density: 2.695±0.007 gm/cm^3 (unannealed)
2.699±0.002 gm/cm^3 (annealed)

Viscosity: $Log_{10}\ \eta = -2.85 + \frac{4205.5}{T - 458.28}$

Where η = viscosity in poises
T = temperature in degrees kelvin

T (100 poise) = 1049±5°C

Upper linear expansion coefficient: 99.02×10^{-6}/°C
Lower linear expansion coefficient: 10.76×10^{-6}/°C

Dilatometric glass transition temperature (T_G): 469±5°C
DSC glass transition temperature (T_G): 472±3°C
Dilatometric softening point (T_D): 506±5°C

Heat capacity (Cp): Cp (150°C) = 0.791
Cp (400°C) = 0.825

Lower Annealing Point (LAP): 453±5°C
Upper Annealing Point (UAP): 484±5°C

TABLE 17: ANNEALING RANGE VISCOSITY DATA: WV-205

Temperature (°C)	Viscosity (Poises)	Log_{10} Viscosity
468±5	1.6888×10^{12}±4%	12.23
471.5	8.2238×10^{11}	11.21
473	7.0674×10^{11}	11.85
475.5	5.4104×10^{11}	11.73
477	3.4266×10^{11}	11.53
479	2.9371×10^{11}	11.47
481	1.9988×10^{11}	11.30
483	1.6705×10^{11}	11.22
485	1.2624×10^{11}	11.10
486	1.1422×10^{11}	11.06
487	1.0279×10^{11}	11.01
489	8.5665×10^{10}	10.93
490	6.3524×10^{10}	10.80
492	6.0387×10^{10}	10.78
493	5.1760×10^{10}	10.71

Notes: - Above data were obtained using a beam bending viscometer.
- Instrument was calibrated using NBS SRM-711.

TABLE 18: HIGH TEMPERATURE VISCOSITY DATA

Temperature (°C)	1/T (°C^{-1})	Viscosity (Poises)	Log_{10} Viscosity
1.023.5±5	9.770×10^{-4}	147.20±5%	2.1679
1039.0	9.625×10^{-4}	121.78	2.0856
1048.5	9.537×10^{-4}	100.63	2.0027
1056.0	9.470×10^{-4}	90.19	1.9551
1062.0	9.416×10^{-4}	86.24	1.9357
1073.5	9.315×10^{-4}	74.75	1.8736
1093.5	9.145×10^{-4}	65.81	1.8183
1102.5	9.070×10^{-4}	59.60	1.7752
1106.5	9.038×10^{-4}	57.05	1.7563

T_{100} Poise = 1049±5°C

Notes: - Above data were obtained using a rotating spendle viscometer
- The instrument used was calibrated using NBS SRM-711

TABLE 19: GLASS TRANSITION TEMPERATURES

Waste Loading/Zeolite Loading (Wt. %)	Glass Transition Temperature (±5°C)
32.0/0	451.3
25.0/0	452.3
20.0/0	453.6
23.0/0	456.6
28.0/9.3	461.3
20.0/6.7	463.3
30.0/10.0	463.6
25.0/12.5	464.0
27.0/9.0	464.3
23.0/11.5	464.5
24.8/10.8	464.7
28.8/12.5	464.7
26.8/11.7	465.3
23.0/23.0	465.6
21.0/9.1	466.6
18.0/18.0	468.2
22.0/11.0	468.6
25.0/12.5	470.5
18.0/18.0	470.6
20.0/20.0	478.7
15.0/30.0	486.9
20.0/40.0	489.2
18.0/36.0	494.3
22.0/44.0	494.8

TABLE 20: HEAT CAPACITY (C_p) OF WV-205

Temperature (°C)	C_p $\frac{J}{g \cdot K}$
100	0.756±2%
150	0.791
200	0.797
250	0.808
300	0.815
350	0.822
400	0.825
450	0.842
458	0.859
467	0.887
475	0.928
483	1.010
492	1.140
500	1.255
504	1.263
508	1.255
517	1.176
525	1.134
533	1.117
542	1.100
550	1.090
600	1.080

Notes:
- C_p data was collected on a differential scanning calorimeter (DSC), at a heating rate of 20°C/min
- Sample size was 12.40 mg
- Sample cell was calibrated with a sapphire standard

TABLE 21: CHEMICAL COMPOSITION REQUIREMENTS FOR TYPE 304 STAINLESS STEEL (S30400)*

ELEMENT	PERCENT
C	0.08
Mn	2.00
P	0.045
S	0.030
Si	1.00
Cr	18.00-20.00
Ni	8.00-10.50
N	0.10
Fe	Bal

* Maximum values unless range is indicated.

TABLE 22: TEMPERATURE DISTRIBUTION IN THE CANISTER

Radial Distance (cm) at Midplane	Temperature °C
0.0	44.9
2.50	44.8
5.00	44.5
10.00	43.3
15.00	41.3
20.00	38.6
25.00	35.0
30.50	30.06
30.67	30.05
30.84	30.04

Axial Distance (cm) at Center Line	Temperature °C
0.0	30.32
0.24	30.33
0.48	30.35
25.24	41.66
50.00	44.36
100.00	44.91
200.00	44.74
304.92	35.13
305.16	35.10
305.40	35.07

TABLE 23: FISSIONABLE MATERIAL CONTENT OF A CANISTER OF WVDP HLW

Radionuclide	Mass (g) Nominal	Range	
233-U	4.0E+2	3.6E+2	4.4E+2
235-U	1.9E+2	1.7E+2	2.1E+2
239-Pu	1.1E+2	9.8E+1	1.2E+2
241-Pu	3.1E+0	2.7E+0	3.5E+0
244-Cm	1.1E+0	5.0E-1	1.7E+0

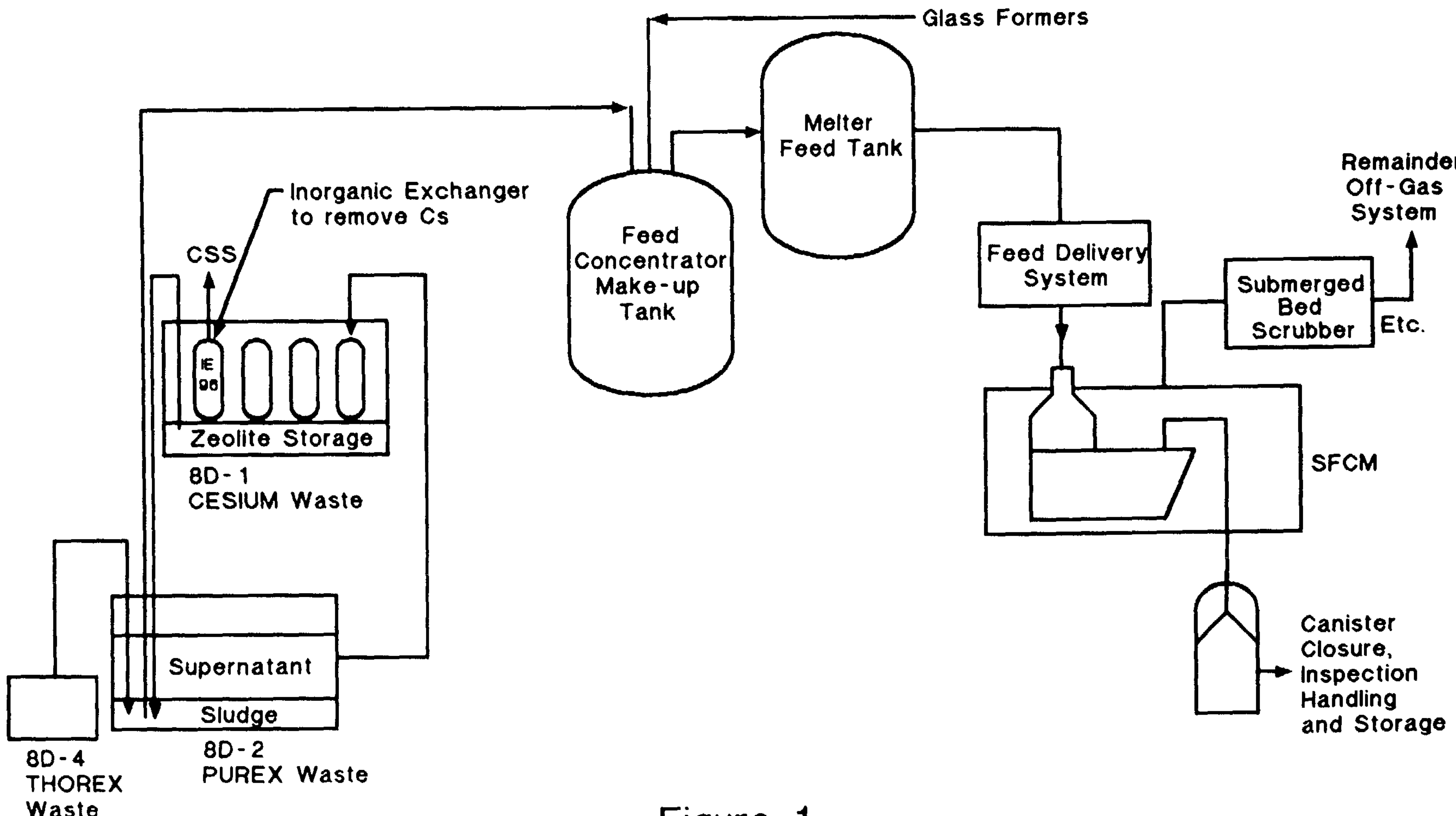

Figure 1
West Valley HLW Processing Flow Sheet

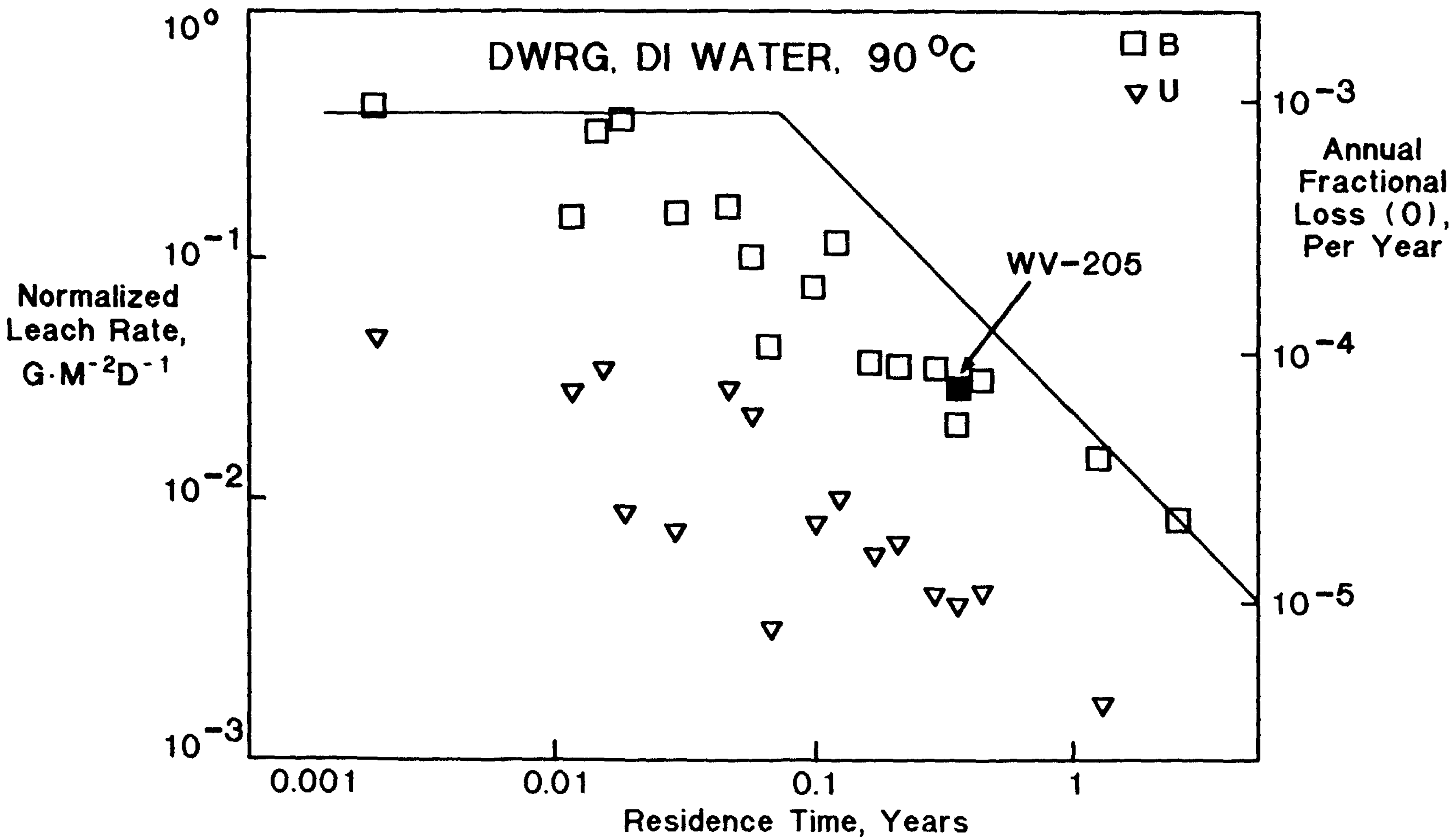

Figure 2

Flow Test Results

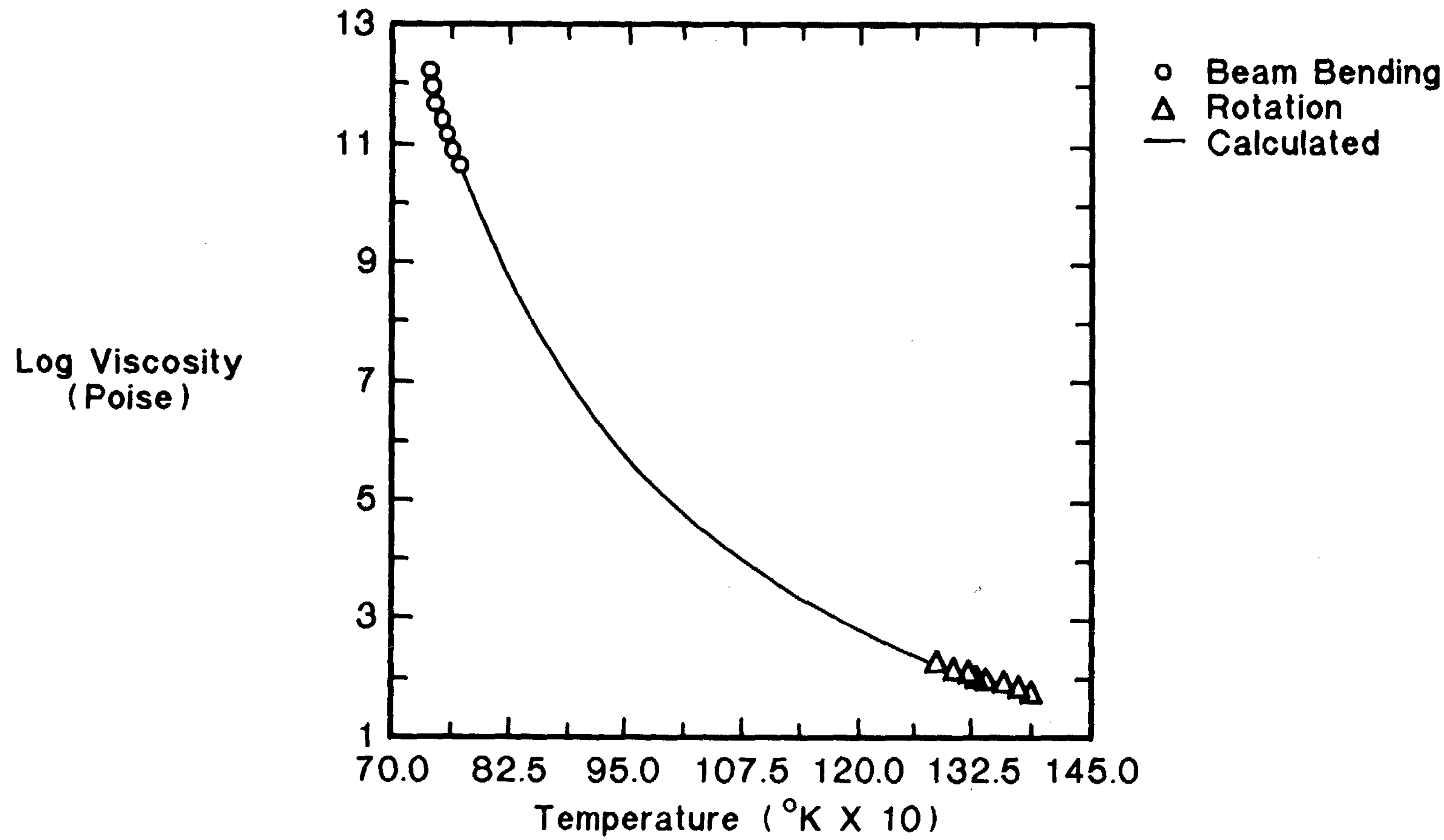

Figure 3
Viscosity Versus Temperature for WV-205

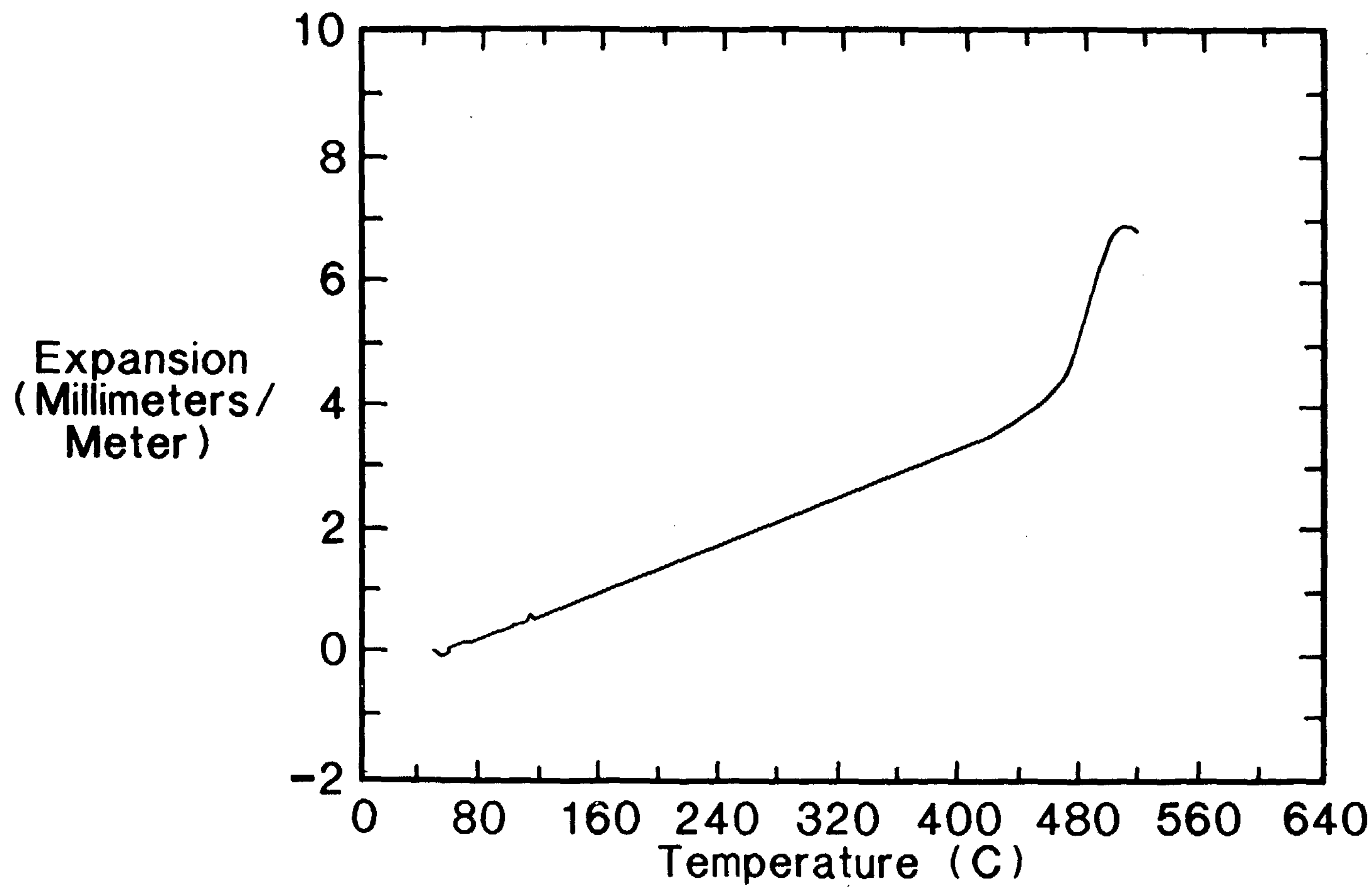

Figure 4
Linear Thermal Expansion Versus Temperature for WV-205

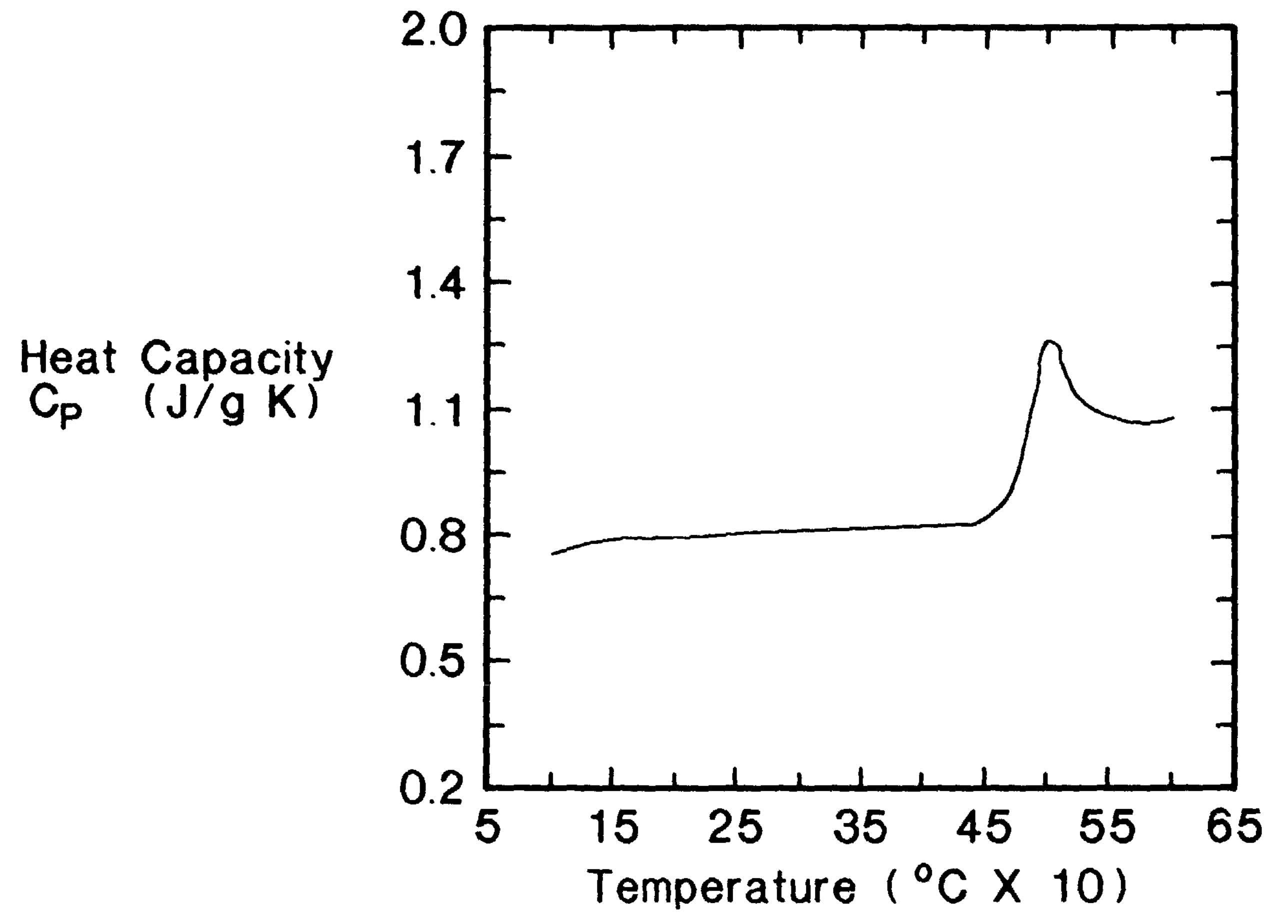

Figure 5
Heat Capacity Versus Temperature for WV-205

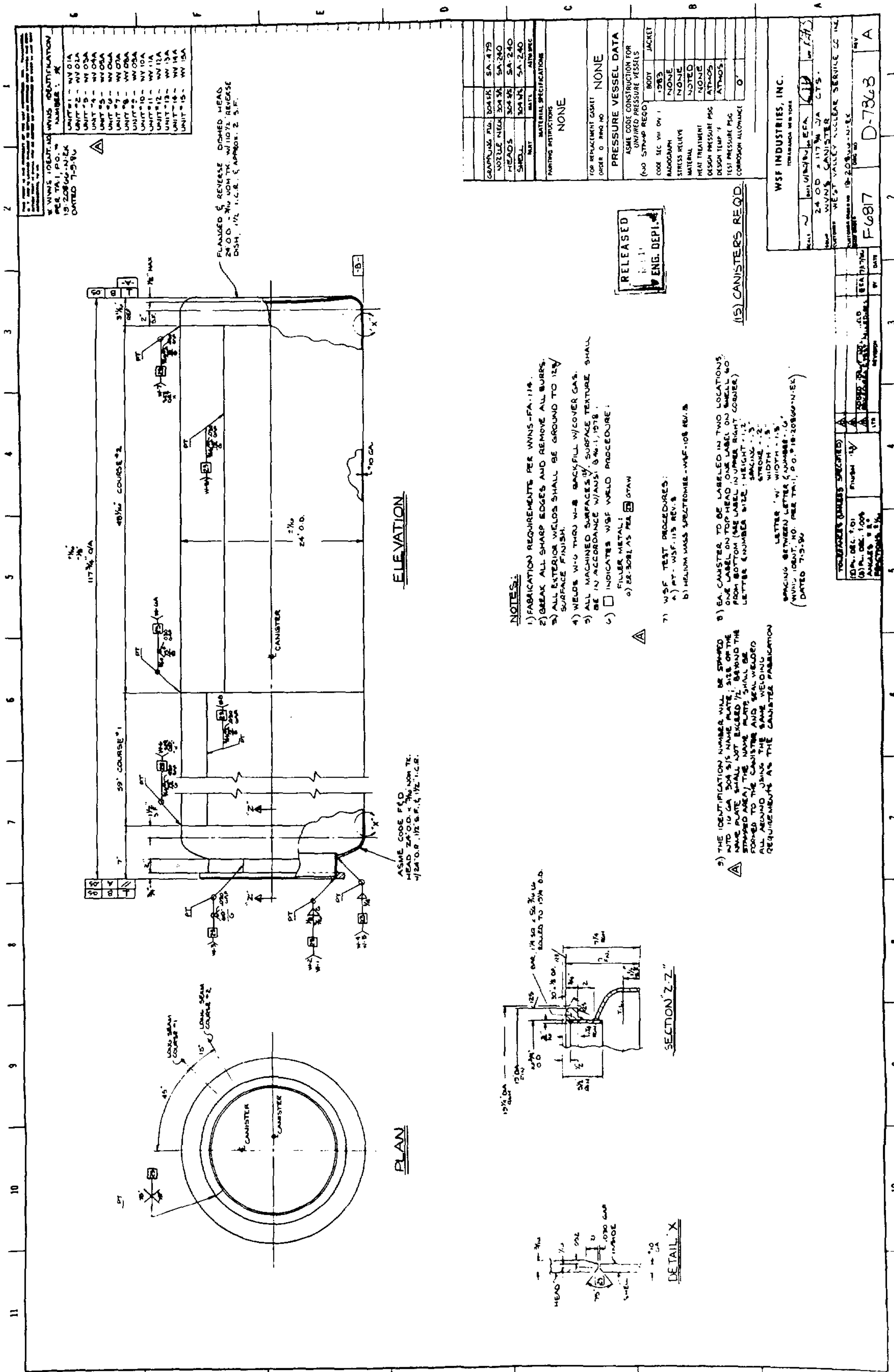

Figure 6
CTS WVNS Canister

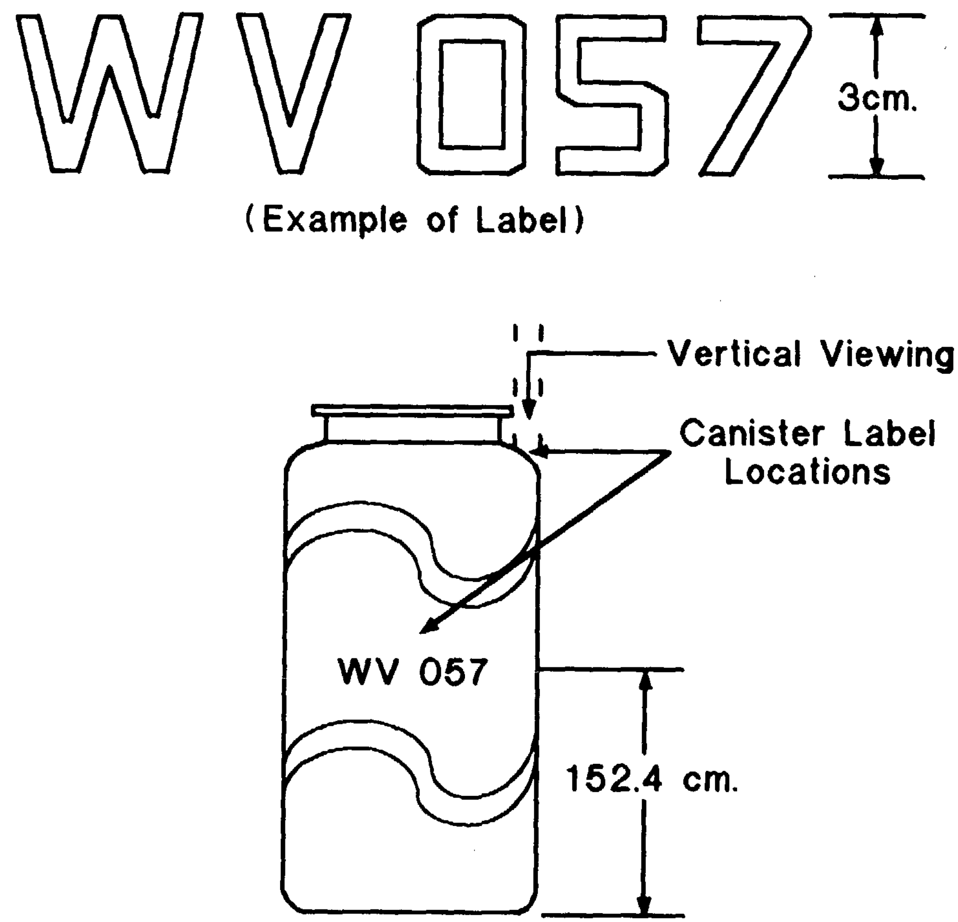

Figure 7
West Valley HLW Canister Labeling

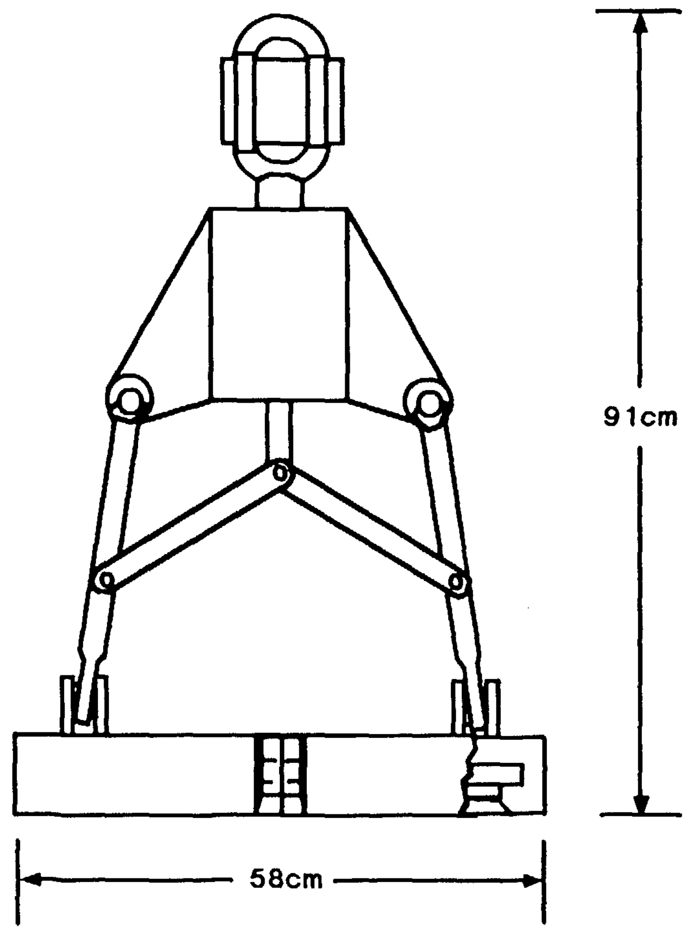

Figure 8
WVNS Canister Grapple

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DESCRIPTION OF THE WEST VALLEY DEMONSTRATION PROJECT REFERENCE HIGH-LEVEL WASTE FORM AND CANISTER

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